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SURVIVAL ESTIMATES FOR THE PASSAGE OF JUVENILE SALMONIDS THROUGH SNAKE RIVER DAMS AND RESERVOIRS, 1997

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SURVIVAL ESTIMATES FOR THE PASSAGE OF JUVENILE SALMONIDS THROUGH SNAKE RIVER DAMS AND RESERVOIRS, 1997

ANNUAL REPORT

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EXECUTIVE SUMMARY

This report consists of two parts describing research activities completed during 1997 under Bonneville Power Administration Project Number 93-29. Part 1 provides reach survival and travel time estimates for 1997 for PIT-tagged hatchery steelhead and yearling chinook salmon in the Snake and Columbia Rivers. The results are reported primarily in the form of tables and figures with a minimum of text. More detailed information on methodology and the statistical models used in the analysis are provided in previous annual reports cited in the text. Analysis of the relationships among travel time, survival, and environmental factors for 1997 and previous years of the study will be reported elsewhere. Part 2 of this report describes research to determine areas of loss and delay for juvenile hatchery salmonids above Lower Granite Reservoir.

Part 1 Summary

In 1997, the National Marine Fisheries Service and the University of Washington completed the fifth year of a study to estimate survival of juvenile salmonids (*Oncorhynchus* spp.) passing through dams and reservoirs on the Snake River. Actively migrating steelhead smolts (*O. mykiss*) were collected at Lower Granite Dam, tagged with passive integrated transponder (PIT) tags, and released to continue their downstream migration. Hatchery steelhead were PIT tagged and released in proportion to the number arriving at the dam. We did not PIT tag any yearling chinook salmon (*O. tshawytscha*) in 1997, due to low numbers migrating out of the Snake River Basin. Instead, we used PIT-tagged fish released from Snake River Basin hatcheries to estimate survival of yearling chinook salmon through the hydroelectric system. PIT-tagged smolts were detected at detection facilities at Lower Granite, Little Goose, Lower Monumental, McNary, John Day and Bonneville Dams. Survival estimates were calculated using the Single-Release Model.

Research objectives in 1997 were 1) to estimate reach and project survival in the Snake River throughout the hatchery steelhead and yearling chinook salmon migrations, and 2) to evaluate the survival-estimation models under prevailing operational and environmental conditions in the Snake River.

During the spring outmigration, slide gates triggered by PIT-tag detectors in juvenile collection facilities at Lower Granite, Little Goose, Lower Monumental, and McNary Dams automatically returned most PIT-tagged smolts back to the river. This allowed detections at multiple downstream dams of PIT-tagged salmonids released from hatcheries and trap sites upstream or from Lower Granite Dam. PIT-tag detection rates varied widely in 1997, due at least in part to the effects of fluctuating levels of spill. Increased spill resulted in lower detection probabilities and decreased precision in survival estimates.

Precise survival estimates for most of the 1997 steelhead and yearling chinook salmon migrations were obtained. Hatchery (87% of steelhead in the analysis were hatchery-reared and

89% of yearling chinook salmon) and wild (13% of steelhead were wild and 11%of yearling chinook salmon) fish were combined in the analyses. Estimated survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam averaged 97.0% for steelhead and 95.6% for yearling chinook salmon. From Little Goose Dam tailrace to Lower Monumental Dam tailrace, estimated survival averaged 90.3% and 89.8% for steelhead and yearling chinook salmon, respectively, and from Lower Monumental Dam tailrace to McNary Dam tailrace, estimated survival averaged 84.4% and 82.7% for steelhead and yearling chinook salmon, respectively. It was not possible to estimate survival probabilities to John Day Dam tailrace in 1997, because insufficient numbers of PIT-tagged fish were detected at John Day and Bonneville Dams.

Part 2 Summary

In 1997, the National Marine Fisheries Service expanded the scope of ongoing juvenile salmonid survival studies, using radio telemetry to determine areas of loss and delay for downstream-migrating hatchery yearling chinook salmon above Lower Granite Reservoir. Research objectives were to 1) identify where losses to the hatchery population occur, calculate travel times, and collect information on dispersal and migration behavior for hatchery-reared yearling chinook salmon above Lower Granite Reservoir, 2) compare travel times, survival estimates, and growth of hatchery-reared yearling chinook salmon with surgically implanted radio tags to those with PIT tags to evaluate the effects of the radio tag on fish performance.

A total of 129 yearling chinook salmon were surgically implanted with a combination radio transmitter/PIT-tag at Lookingglass Hatchery during early March. An additional 470 fish were surgically implanted with a combination sham-radio transmitter/PIT-tag to supplement the sample size of “radio-tagged fish.” Survival estimates, travel times, and growth of radio-tagged fish were compared with fish from Lookingglass Hatchery marked only with PIT tags. All fish were released with the Lookingglass Hatchery production release on 7 April.

Passage of radio-tagged fish as they migrated downstream was monitored by twelve fixed-site telemetry receivers between Lookingglass Hatchery and the Snake River smolt monitoring trap at the head of Lower Granite Reservoir. Individual smolts were subsequently detected at PIT-tag detection facilities at Lower Granite, Little Goose, Lower Monumental, McNary, and Bonneville Dams. In addition, a subsample of Lookingglass Hatchery radio-tagged and PIT-tagged fish were recaptured at Little Goose Dam and measured and weighed for comparison of growth.

A high percentage of radio transmitters used in this study malfunctioned because water leaked into them, thus reducing the quantity of data collected. In addition, mortality for surgically radio-/sham-tagged fish between tagging and release was unacceptably high. The majority of the hatchery production population and of radio-tagged fish that survived to release did not leave the hatchery raceways during the 24-hour volitional release period and had to be physically crowded out of the raceways. After release, 10 radio-tagged fish subsequently located downstream from the mouth of Lookingglass Creek remained near the hatchery release pipe in

Lookingglass Creek for a median of 76 hours. Fish that exited Lookingglass Creek soon after release migrated rapidly downstream in a concentrated group until reaching the confluence of the Grande Ronde and Snake Rivers. Upon entering the Snake River, individual radio-tagged fish delayed for varying amounts of time and the group became dispersed. During the migration, confirmed mortalities for radio-tagged fish were 15.2% in Lookingglass Creek, 4.5% in the Grande Ronde River, and 9.1% in the Snake River. Specific areas of concentrated losses were within 3 km of Lookingglass Hatchery in Lookingglass Creek and a 23-km section of the Snake River below the confluence of the Grande Ronde River. No mortalities were confirmed in the transition area between the free-flowing Snake River and Lower Granite Dam Reservoir.

Radio-tagged fish had a lower survival estimate and shorter median travel time than PIT-tagged fish between Lookingglass Hatchery and the tailrace of Lower Granite Dam. Radio-tagged fish grew at a slower rate than the PIT-tagged fish between the time of tagging at the hatchery and the time of recapture at Little Goose Dam. Therefore, the radio-tagged fish may not have been representative of the Lookingglass Hatchery population. Migratory behavior and survival were likely affected by both the tagging process itself and the presence of an implanted tag during migration.

This study provided information on areas of delay during migration and specific areas where mortality occurred. We believe the high mortality prior to release was in part due to bacterial kidney disease (*Renibacterium salmoninarum*) (BKD), which may have been aggravated by the stress associated with the surgical implant technique. Stress associated with the tagging procedure and susceptibility to BKD during recovery might be lessened by using smaller radio tags, and reducing the post-surgical residence time in hatchery raceways before release.

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Part 1

Reach Survival and Travel Time Estimates for PIT-tagged Hatchery Steelhead and Yearling Chinook Salmon in the Snake and Columbia Rivers, 1997

INTRODUCTION

Survival estimates for juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) that migrate through reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers are essential to develop effective strategies for recovering depressed stocks. Many current management strategies, however, rely on outdated estimates of system survival (Raymond 1979, Sims and Ossiander 1981) that lacked statistical precision and that were derived in a river system considerably different from today's (Williams and Matthews 1995). Knowledge of the magnitude, locations, and causes of smolt mortality under present passage conditions, and under conditions projected for the future, are necessary to develop strategies that will optimize smolt survival during migration.

From 1993 through 1996, the National Marine Fisheries Service (NMFS) and the University of Washington (UW) demonstrated the feasibility of using three statistical models to estimate survival of PIT-tagged (Prentice et al. 1990a) juvenile salmonids passing through Snake River dams and reservoirs (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998). Evaluation of assumptions for these models indicated that all were generally satisfied, and accurate and precise survival estimates were obtained.

In 1997, NMFS and UW completed the fifth year of the study. Research objectives were 1) to estimate reach and project survival in the Snake River throughout the yearling chinook salmon and steelhead migrations, and 2) to evaluate the performance of the survival-estimation models under prevailing operational and environmental conditions in the Snake River.

METHODS

Experimental Design

The Single-Release (SR) Model was used to estimate survival from PIT-tag data in 1997 (Cormack 1964, Jolly 1965, Seber 1965). Iwamoto et al. (1994) presented background information and underlying statistical theory.

During the 1997 migration season, automatic PIT-tag detectors (Prentice et al. 1990a,b,c) were operational in the juvenile bypass systems at Lower Granite (RKm 695), Little Goose (RKm 635), Lower Monumental (RKm 589), and McNary Dams (RKm 470) (Fig. 1). Further, the majority of PIT-tagged fish detected at dams below Lower Granite Dam were diverted back to the river by slide gates (rather than being barged or trucked downstream), which allowed for the possibility of detection of a particular fish at more than one downstream site. (Most PIT-tagged fish detected at Lower Granite Dam were transported for the multi-state comparative survival study). A portion of the smolts passing John Day and Bonneville Dams were also interrogated for PIT tags.

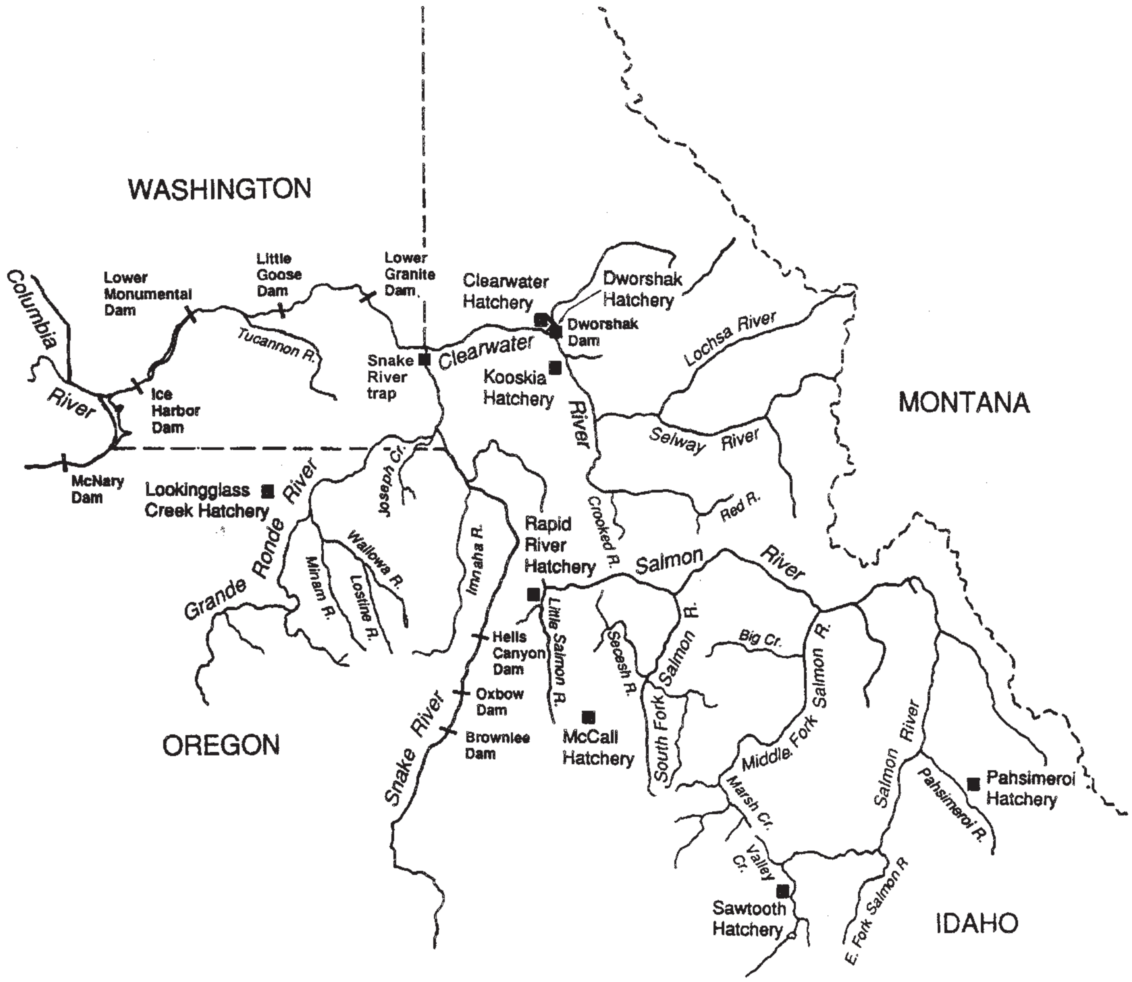

Figure 1. Study area showing release and detection sites.

We used the records of downstream PIT-tag detections in the SR Model to estimate survival from the point of release to Lower Granite Dam tailrace, from Lower Granite Dam tailrace to Little Goose Dam tailrace, and from Little Goose Dam tailrace to Lower Monumental Dam tailrace. In some cases, there were sufficient detections at John Day and Bonneville Dams to estimate survival in the river section from Lower Monumental Dam tailrace to McNary Dam tailrace. There were not sufficient detections to estimate survival from McNary Dam to John Day Dam.

Lower Granite Dam Tailrace Release Groups

During 1997, hatchery steelhead were collected in the juvenile collection facility at Lower Granite Dam, PIT tagged, and released to the tailrace. Methods for collecting, tagging, and releasing hatchery steelhead were the same as used in past years of this study (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998). Steelhead were PIT-tagged in approximate proportion to their arrival at Lower Granite Dam throughout the migration season. Daily tailrace release groups were pooled into weekly groups. No yearling chinook salmon were PIT tagged specifically for this study, due to low numbers of previously untagged fish arriving at Lower Granite Dam during 1997. Large numbers were already tagged for other studies upstream from Lower Granite Dam. For both steelhead and yearling chinook salmon tagged above Lower Granite Dam then detected at Lower Granite Dam and returned to the tailrace, we created daily "release groups" according to the day they were detected at Lower Granite Dam. For these groups leaving Lower Granite Dam, we estimated survival from the Lower Granite Dam tailrace to points downstream.

Hatchery Releases

In 1997, most hatcheries in the Snake River Basin released PIT-tagged fish as part of research separate from the NMFS/UW survival study. We analyzed data from hatchery releases of PIT-tagged fish to provide estimates of survival for yearling chinook salmon during 1997. In the course of characterizing the various hatchery releases, preliminary analyses were performed to determine whether data from multiple releases could be pooled to increase sample sizes. We neither intended nor attempted to analyze the experiments for which the hatchery releases were made.

For each hatchery, each set of releases was examined to determine suitability for survival analysis, and release groups were pooled where appropriate. The SR Model was applied to each resulting data set to estimate the same probabilities as for our Lower Granite Dam tailrace releases. Survival estimates were not calculated for releases of hatchery and wild chinook salmon PIT tagged as parr because release and detection numbers were not sufficient.

Data Analysis

Tagging and detection data were retrieved from the PIT Tag Information System (PTAGIS) maintained by the Pacific States Marine Fisheries Commission.[1] Data were examined for erroneous records, inconsistencies, and data anomalies. Records were eliminated where appropriate, and all eliminated PIT-tag codes were recorded with the reasons for their elimination. For each remaining PIT-tag code, we constructed a record ("capture history") indicating at which dams the tagged fish was detected and at which it was not detected. Methods for data retrieval, database quality assurance/control, and construction of capture histories were the same as those used in past years (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998).

Tests of Assumptions

As in past years, an important objective of the studies in 1997 was to test the statistical validity of the SR Model as applied to the data generated from PIT-tagged juvenile salmonids in the Snake River. Validity of the model was tested by evaluating critical assumptions and all were generally met during 1997.

Survival Estimation

Estimates of survival probabilities under the SR Model are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0. For practical purposes estimates should be considered equal to 1.0 in these cases.

When estimates for a particular river section or passage route were available from more than one release or pairs of releases, the estimates were often combined using a weighted average. Weights were inversely proportional to the respective estimated relative variances (coefficient of variance squared). The variance of an estimated survival probability from the SR Model is a function of the estimate itself, that is, lower survival estimates tend to have smaller estimated variance. Consequently, when estimated absolute variances are used in weighting, lower survival estimates tend to have disproportionate influence on the resulting weighted mean.

A statistical computer program for analyzing release-recapture data was used to perform all survival analyses. This program was developed at the University of Washington and named SURPH, for "Survival with Proportional Hazards" (Skalski et al. 1993, Smith et al. 1994).

Travel Time

Travel times were calculated for hatchery steelhead from 1) Lower Granite Dam to Little Goose Dam, 2) Little Goose Dam to Lower Monumental Dam, and 3) Lower Monumental Dam

[1] Pacific States Marine Fisheries Commission, PIT Tag Operations Center, 45 SE 82nd Drive, Suite 100, Gladstone, OR 97207.

to McNary Dam. Travel time between any two dams was calculated for each fish detected at both dams as the number of days between last detection at the upstream dam and first detection at the downstream dam. Travel time included the time required to move through the reservoir to the forebay of the downstream dam and any delay associated with residence in the forebay before entry into the bypass system.

To facilitate comparisons among the three river sections, rate of migration in each section (kilometers per day) was also calculated. Lengths of the river sections are 60 km from Lower Granite Dam to Little Goose Dam, 43 km from Little Goose Dam to Lower Monumental Dam, and 119 km from Lower Monumental Dam to McNary Dam. Rate of migration through a river section was calculated as the length of the section (km) divided by the travel time (days) (which included any delay at dams as noted above). The minimum, 20th percentile, median, 80th percentile, and maximum travel times and migration rates were determined from the distributions for each release group.

The true complete set of travel times for a release group includes travel times of both detected and undetected fish. However, using PIT tags, travel times cannot be determined for fish that traverse a river section but are not detected at one or both ends of the section. Thus, travel time statistics were computed from travel times for detected fish only, representing a sample of the complete set. During 1997, substantial spill volumes occurred at all dams, resulting in lower detection rates. Some release groups had fish passing detector dams both before and after large spill volumes began. For these groups, the faster migrants were sampled more heavily than the slower migrants because they arrived at the dam during the earlier period of lighter spill when detection rates were higher. Thus, the distributions of observed travel times for these groups were biased toward shorter travel times, or faster migration rates.

RESULTS

Lower Granite Dam

Hatchery steelhead were PIT tagged at Lower Granite Dam from 14 April to 3 June (Table 1). A total of 22,112 hatchery steelhead were handled, of which 19,636 were PIT-tagged and released. Mortality from handling and tagging averaged less than 0.2%. An additional 13,443 PIT-tagged steelhead (11,724 hatchery origin, 1,719 wild) that had been released above Lower Granite Dam were detected and returned to the Snake River by the slide gates at Lower Granite Dam between 8 April and 2 June. Similarly, between 6 April and 31 May, a total of 7,588 PIT-tagged yearling chinook salmon (6,741 hatchery origin, 847 wild) that had been released upstream were detected and returned to the river at Lower Granite Dam.

Survival Estimation -- Lower Granite Dam Tailrace Releases

Survival probabilities were estimated for daily and weekly groups of steelhead released in the tailrace at Lower Granite Dam for eight consecutive weeks from 8 April through 2 June

Table 1. Numbers of fish handled (N) and mortalities (morts) while PIT tagging hatchery steelhead at Lower Granite Dam for survival studies in 1997. Overall percent mortality is also shown.

Tag Date	Hat. steelhead		Wild steelhead		Hat. chinook		Wild chinook		Sockeye	
	N	Morts	N	Morts	N	Morts	N	Morts	N	Morts
14 Apr	163	2	9	0	1	0	5	0	0	0
15 Apr	184	1	12	0	2	0	0	0	0	0
16 Apr	164	0	9	0	4	0	8	0	0	0
17 Apr	152	0	7	0	2	0	2	0	0	0
18 Apr	160	0	16	0	12	0	11	0	0	0
20 Apr	789	0	189	0	383	0	62	0	2	0
22 Apr	780	4	85	0	31	0	9	0	0	0
23 Apr	764	5	82	0	9	1	7	0	0	0
24 Apr	722	2	128	0	11	0	1	0	0	0
25 Apr	766	0	44	0	8	0	4	0	0	0
28 Apr	1,005	0	76	0	21	0	2	0	0	0
29 Apr	1,098	0	63	0	13	0	4	0	0	0
30 Apr	1,032	2	64	0	45	0	5	0	0	0
1 May	1,077	0	36	0	13	0	0	0	0	0
2 May	1,072	6	39	0	23	0	4	0	0	0
5 May	1,010	2	26	0	49	0	6	0	1	0
6 May	1,007	1	41	0	4	0	0	0	0	0
7 May	1,084	5	72	1	58	0	6	0	1	0
8 May	1,250	4	83	0	40	0	1	0	0	0
9 May	1,134	1	63	0	4	0	2	0	0	0
12 May	994	0	35	0	4	0	0	0	0	0
13 May	947	5	57	0	2	0	1	0	0	0
14 May	926	3	39	0	2	1	4	0	0	0
15 May	1,089	5	91	0	24	0	14	0	0	0
16 May	1,051	0	72	0	17	0	7	0	0	0
19 May	200	0	0	0	0	0	0	0	0	0
20 May	200	0	0	0	0	0	0	0	0	0
21 May	200	0	0	0	0	0	0	0	0	0
22 May	194	0	0	0	0	0	0	0	0	0
23 May	201	0	0	0	0	0	0	0	0	0
26 May	100	0	0	0	0	0	0	0	0	0
27 May	102	0	0	0	0	0	0	0	0	0
28 May	101	0	0	0	0	0	0	0	0	0
29 May	102	0	0	0	0	0	0	0	0	0
30 May	101	0	0	0	0	0	0	0	0	0
2 June	99	0	0	0	0	0	0	0	0	0
3 June	142	0	0	0	0	0	0	0	0	0
Total	22,112	48	1,438	1	782	2	165	0	4	0
Percent		0.2		0.1		0.3		0.0		0.0

(including hatchery and wild steelhead PIT-tagged and released above Lower Granite Dam) (Table 2). Weighted averages of survival estimates for daily groups (Appendix Table 1) were calculated. Survival estimates from Lower Granite Dam tailrace to Little Goose Dam tailrace averaged 0.966 (s.e. 0.006) (Table 2). From Little Goose Dam tailrace to Lower Monumental Dam tailrace, estimated survival averaged 0.902 (s.e. 0.020). From Lower Monumental Dam tailrace to McNary Dam tailrace, estimated survival averaged 0.834 (s.e. 0.065). For the longest reach possible, Lower Granite Dam tailrace to McNary Dam tailrace, estimated survival averaged 0.728 (s.e. 0.053). Detection probability estimates for weekly groups were also calculated (Table 3).

Survival probabilities were estimated for weekly groups of yearling chinook salmon (hatchery and wild combined) from upstream releases detected at Lower Granite Dam and returned to the tailrace for eight consecutive weeks from 6 April through 31 May. Weighted averages of survival estimates for daily groups (Appendix Table 2) were: 0.942 (s.e. 0.018) from Lower Granite Dam tailrace to Little Goose Dam tailrace (Table 4); 0.894 (s.e. 0.042) from Little Goose Dam tailrace to Lower Monumental Dam tailrace; and 0.798 (s.e. 0.091) from Lower Monumental Dam tailrace to McNary Dam tailrace. For the longest reach possible, Lower Granite Dam tailrace to McNary Dam tailrace, estimated survival averaged 0.653 (s.e. 0.072). Detection probability estimates for these groups were also calculated (Table 5).

Survival Estimation -- Hatchery Releases

For PIT-tagged hatchery yearling chinook salmon released from Snake River Basin hatcheries in 1997, we estimated survival probabilities to the Snake River trap at the head of Lower Granite Reservoir and downstream dams and detection probabilities at the detection sites (Tables 6 and 7, respectively).

Survival Estimation -- Fish Trap Releases

Survival probability estimates for juvenile salmonids PIT-tagged and released from Snake River Basin traps in 1997 are shown in Table 8.

Travel Time

Travel time and migration rate statistics for juvenile steelhead and yearling chinook salmon released in the tailrace of Lower Granite Dam are given in Tables 9 through 12. For hatchery steelhead, migration rates were highest in the lower river sections. Migration rates generally increased over time as flows, water temperatures, and levels of spill increased, and as fish presumably became more smolted. Data were insufficient to determine whether migration rates for yearling chinook salmon showed a similar pattern.

Comparison of Survival Estimates, 1993-97

Estimates of survival from Snake River Basin hatcheries to Lower Granite Dam tailrace

Table 2. Estimated survival probabilities for juvenile steelhead (hatchery and wild combined) detected and returned to or PIT tagged and released into the tailrace of Lower Granite Dam in 1997. Daily groups pooled weekly. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Date at LGR	Number released	LGR to LGO	LGO to LMO	LMO to MCN	LGR to LMO	LGR to MCN
08 Apr - 14 Apr	272	0.928 (0.065)	1.0[a] (0.242)	0.711 (0.384)	1.0[a] (0.211)	0.802 (0.404)
15 Apr - 21 Apr	2,888	0.990 (0.017)	0.871 (0.040)	0.841 (0.132)	0.863 (0.037)	0.725 (0.110)
22 Apr - 28 Apr	4,536	0.986 (0.016)	0.922 (0.037)	0.655 (0.079)	0.909 (0.032)	0.595 (0.069)
29 Apr - 05 May	8,076	0.974 (0.010)	0.888 (0.022)	0.890 (0.099)	0.865 (0.020)	0.770 (0.084)
06 May - 12 May	7,258	0.946 (0.012)	0.978 (0.037)	0.904 (0.154)	0.926 (0.033)	0.836 (0.139)
13 May - 19 May	5,935	0.967 (0.021)	0.928 (0.056)	1.0[a] (0.250)	0.898 (0.050)	1.0[a] (0.218)
20 May - 26 May	2,213	0.993 (0.029)	0.774 (0.052)	1.0[a] (0.661)	0.769 (0.046)	1.0[a] (0.503)
27 May - 02 Jun	1,658	0.934 (0.033)	0.816 (0.076)	0.714 (0.300)	0.762 (0.066)	0.544 (0.224)
Weighted Mean[b]	32,367	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.871 (0.016)	0.728 (0.053)

[a] Model-based estimate greater than 1.0.

[b] Weighted means of the independent estimates for daily groups (7 April-31 May), with weights inversely proportional to respective estimated relative variances (see Appendix Table 1).

Table 3. Estimated detection probabilities for juvenile steelhead (hatchery and wild combined) detected and returned to or PIT tagged and released into the tailrace of Lower Granite Dam in 1997. Daily groups pooled weekly. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Date at LGR	Number released	LGO	LMO	MCN
08 Apr - 14 Apr	272	0.436 (0.043)	0.336 (0.069)	0.167 (0.088)
15 Apr - 21 Apr	2,888	0.533 (0.013)	0.480 (0.023)	0.114 (0.019)
22 Apr - 28 Apr	4,536	0.454 (0.010)	0.496 (0.019)	0.150 (0.019)
29 Apr - 05 May	8,076	0.495 (0.007)	0.572 (0.014)	0.117 (0.013)
06 May - 12 May	7,258	0.504 (0.009)	0.449 (0.017)	0.065 (0.011)
13 May - 19 May	5,935	0.402 (0.011)	0.311 (0.018)	0.047 (0.011)
20 May - 26 May	2,213	0.407 (0.016)	0.529 (0.033)	0.045 (0.019)
27 May - 02 Jun	1,658	0.420 (0.019)	0.484 (0.044)	0.080 (0.034)

Table 4 Estimated survival probabilities for yearling chinook salmon (hatchery and wild combined) detected and returned to the tailrace of Lower Granite Dam in 1997. Daily groups pooled weekly. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Date at LGR	Number released	LGR to LGO	LGO to LMO	LMO to MCN	LGR to LMO	LGR to MCN
06 Apr - 12 Apr	201	0.806 (0.060)	1.0[a] (0.162)	0.911 (0.554)	0.820 (0.121)	0.748 (0.442)
13 Apr - 19 Apr	539	0.978 (0.060)	1.0[a] (0.273)	0.532 (0.297)	1.0[a] (0.251)	0.647 (0.333)
20 Apr - 26 Apr	1,277	0.924 (0.039)	0.856 (0.071)	1.0[a] (0.357)	0.787 (0.058)	0.969 (0.274)
27 Apr - 03 May	1,714	0.960 (0.033)	0.818 (0.062)	0.789 (0.206)	0.821 (0.060)	0.620 (0.156)
04 May -10 May	1,340	1.0[a] (0.053)	0.977 (0.142)	0.481 (0.173)	0.941 (0.127)	0.483 (0.161)
11 May - 17 May	1,822	0.990 (0.061)	0.952 (0.166)	0.703 (0.290)	0.990 (0.172)	0.663 (0.251)
18 May - 24 May	533	0.942 (0.078)	0.997 (0.219)	NA	0.995 (0.222)	NA
25 May - 31 May	162	0.994 (0.195)	0.892 (0.399)	NA	0.819 (0.320)	NA
Weighted Mean[b]	7,588	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.810 (0.036)	0.653 (0.072)

[a] Model-based estimate greater than 1.0.

[b] Weighted means of the independent estimates for daily groups (6 April-31 May), with weights inversely proportional to respective estimated relative variances (see Appendix Table 1).

Table 5. Estimated detection probabilities for yearling chinook salmon (hatchery and wild combined) detected and returned to the tailrace of Lower Granite Dam in 1997. Daily groups pooled weekly. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Date at LGR	Number released	LGO	LMO	MCN
06 Apr - 12 Apr	201	0.488 (0.051)	0.456 (0.077)	0.255 (0.155)
13 Apr - 19 Apr	539	0.450 (0.035)	0.239 (0.053)	0.153 (0.081)
20 Apr - 26 Apr	1,277	0.376 (0.021)	0.392 (0.032)	0.155 (0.045)
27 Apr - 03 May	1,714	0.409 (0.018)	0.427 (0.031)	0.188 (0.049)
04 May -10 May	1,340	0.359 (0.023)	0.253 (0.036)	0.167 (0.057)
11 May - 17 May	1,822	0.321 (0.023)	0.179 (0.030)	0.078 (0.030)
18 May - 24 May	533	0.340 (0.035)	0.309 (0.066)	NA
25 May - 31 May	162	0.273 (0.064)	0.308 (0.128)	NA

Table 6. Estimated survival probabilities for PIT-tagged yearling chinook salmon released from hatcheries in 1997. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: Rel-Release site; SNT-Snake River Trap; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Hatchery	Number released	Rel to SNT	SNT to LGR	Rel to LGR	LGR to LGO	LGO to LMO	LMO to MCN	Rel to MCN
Kooskia	4,075	NA	NA	0.449 (0.034)	1.0[a] (0.137)	0.557 (0.075)	0.630 (0.207)	0.183 (0.057)
Dworshak	14,080	NA	NA	0.576 (0.017)	1.0[a] (0.046)	0.819 (0.048)	0.655 (0.109)	0.324 (0.051)
Rapid River	40,493	0.391 (0.040)	0.978 (0.103)	0.382 (0.008)	0.971 (0.030)	0.804 (0.030)	1.0[a] (0.135)	0.307 (0.039)
Pahsimeroi	33,479	0.745 (0.372)	0.671 (0.336)	0.500 (0.008)	0.957 (0.027)	0.862 (0.033)	1.0[a] (0.146)	0.449 (0.058)
McCall	52,687	0.415 (0.032)	1.0[a] (0.080)	0.424 (0.008)	0.927 (0.026)	0.887 (0.035)	0.895 (0.110)	0.312 (0.037)
Lookingglass[b]	13,378	0.822 (0.154)	0.750 (0.142)	0.616 (0.017)	0.986 (0.042)	0.777 (0.042)	0.986 (0.200)	0.465 (0.092)
Lookingglass[c]	40,042	0.640 (0.038)	0.936 (0.057)	0.598 (0.010)	0.927 (0.022)	0.833 (0.022)	0.839 (0.069)	0.388 (0.031)

[a] Model-based estimate greater than 1.0.

[b] Released at Imnaha River Weir

[c] Released at Lookingglass Hatchery.

Table 7. Estimated detection probabilities for PIT-tagged yearling chinook salmon released from hatcheries in 1997. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: SNT-Snake River Trap; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Hatchery	Number released	SNT	LGR	LGO	LMO	MCN
Kooskia	4,075	NA	0.265 (0.022)	0.264 (0.022)	0.338 (0.040)	0.171 (0.055)
Dworshak	14,080	NA	0.290 (0.010)	0.361 (0.010)	0.317 (0.018)	0.144 (0.024)
Rapid River	40,493	0.00240 (0.00046)	0.340 (0.007)	0.365 (0.008)	0.362 (0.013)	0.108 (0.014)
Pahsimeroi	33,479	0.00016 (0.00011)	0.380 (0.007)	0.386 (0.008)	0.315 (0.012)	0.122 (0.016)
McCall	52,687	0.00325 (0.00046)	0.333 (0.007)	0.363 (0.007)	0.284 (0.011)	0.095 (0.011)
Lookingglass[a]	13,378	0.00218 (0.00060)	0.318 (0.010)	0.387 (0.011)	0.358 (0.019)	0.104 (0.021)
Lookingglass[b]	40,042	0.00539 (0.00056)	0.318 (0.006)	0.377 (0.006)	0.377 (0.010)	0.183 (0.015)

[a] Released at Imnaha River Weir.

[b] Released at Lookingglass Hatchery.

Table 8. Estimated survival probabilities for juvenile salmonids released from fish traps in Snake River Basin in 1997. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Trap	Release dates	Number released	Release to LGR		LGR to LGO		LGO to LMO		Release to LMO	
Hatchery chinook salmon										
Imnaha	10 Apr - 09 May	955	0.816	(0.047)	0.874	(0.076)	1.0[a]	(0.190)	0.731	(0.128)
Wild chinook salmon										
Imnaha	12 Mar - 07 May	238	0.895	(0.066)	0.994	(0.122)	0.946	(0.195)	0.841	(0.153)
Hatchery steelhead										
Salmon	14 Apr - 07 May	1,252	0.872	(0.017)	1.0[a]	(0.039)	0.897	(0.083)	0.789	(0.068)
Snake	07 Apr - 07 May	1,396	0.963	(0.016)	0.940	(0.030)	0.887	(0.064)	0.803	(0.054)
Imnaha	15 Apr - 27 Jun	5,458	0.807	(0.011)	0.981	(0.026)	0.829	(0.052)	0.656	(0.038)
Wild steelhead										
Salmon	25 Mar - 07 May	59	0.876	(0.062)	0.919	(0.121)	0.762	(0.159)	0.613	(0.114)
Snake	07 Apr - 05 May	129	0.968	(0.051)	0.936	(0.097)	0.739	(0.162)	0.670	(0.136)
Imnaha	15 Apr - 11 Jun	694	0.887	(0.021)	1.0[a]	(0.046)	0.822	(0.080)	0.746	(0.066)

[a] Model-based estimate greater than 1.0.

Table 9. Travel time statistics for juvenile steelhead (hatchery and wild combined) detected and returned to or PIT tagged and released into the tailrace of Lower Granite Dam in 1997. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; BON-Bonneville Dam; N-Number of fish on which statistics are based; Med.-Median.

	LGR to LGO (days)				LGO to LMO (days)				LMO to MCN (days)				LGR to MCN (days)			
Date at LGR	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%
08 Apr - 14 Apr	110	4.6	6.2	14.7	48	1.6	3.3	7.0	9	2.5	3.1	8.4	33	9.8	13.0	21.7
15 Apr - 21 Apr	1,524	2.5	3.3	5.9	612	1.0	1.5	3.3	116	2.3	3.1	4.6	229	6.5	9.0	15.4
22 Apr - 28 Apr	2,031	2.3	3.0	5.0	887	1.0	1.4	3.0	196	2.0	2.7	4.3	394	5.5	7.4	13.4
29 Apr - 05 May	3,892	2.3	3.0	4.5	1,930	1.2	1.9	4.4	406	2.3	3.0	4.7	713	6.4	8.5	13.7
06 May - 12 May	3,462	2.5	3.1	4.7	1,527	1.3	2.2	4.3	186	1.9	2.4	3.8	389	6.2	8.3	11.8
13 May - 19 May	2,306	2.1	2.7	4.6	650	1.0	1.7	3.5	83	1.7	2.0	3.3	268	4.5	6.2	9.8
20 May - 26 May	894	2.1	2.8	4.0	354	1.0	1.5	2.9	67	2.0	2.4	3.6	111	5.5	7.4	10.5
27 May - 02 Jun	650	2.2	2.8	3.7	243	0.9	1.3	2.0	34	1.7	2.2	2.9	68	5.1	6.2	8.1

	LGR to BON (days)			
Date at LGR	N	20%	Med.	80%
08 Apr - 14 Apr	14	15.3	18.8	28.3
15 Apr - 21 Apr	269	9.6	13.6	21.5
22 Apr - 28 Apr	386	9.6	13.5	19.9
29 Apr - 05 May	537	10.0	13.1	18.5
06 May - 12 May	462	9.9	12.1	16.0
13 May - 19 May	366	8.1	10.5	14.7
20 May - 26 May	114	8.4	9.9	12.0
27 May - 02 Jun	63	7.5	8.9	11.7

Table 10. Migration rate statistics for juvenile steelhead (hatchery and wild combined) detected and returned to or PIT tagged and released into the tailrace of Lower Granite Dam in 1997. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; BON-Bonneville Dam; N-Number of fish on which statistics are based; Med.-Median.

	LGR to LGO (km/day)				LGO to LMO (km/day)				LMO to MCN (km/day)				LGR to MCN (km/day)			
Date at LGR	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%
08 Apr - 14 Apr	110	4.1	9.7	13.0	48	6.5	14.1	29.1	9	14.2	38.5	47.2	33	10.4	17.4	23.1
15 Apr - 21 Apr	1,524	10.2	18.0	23.8	612	13.8	29.9	46.9	116	26.2	38.5	51.7	229	14.6	25.1	34.6
22 Apr - 28 Apr	2,031	11.9	20.3	25.8	887	15.2	33.1	47.9	196	28.0	44.9	60.4	394	16.8	30.5	41.2
29 Apr - 05 May	3,892	13.5	20.3	26.2	1,930	10.4	24.5	38.3	406	25.5	39.7	51.1	713	16.4	26.4	35.2
06 May - 12 May	3,462	12.8	19.2	24.4	1,527	10.7	21.0	35.9	186	31.2	49.4	62.3	389	19.1	27.0	36.2
13 May - 19 May	2,306	13.1	22.0	28.6	650	13.3	27.2	47.4	83	36.2	59.2	70.4	268	22.9	36.3	49.8
20 May - 26 May	894	14.9	21.5	28.3	354	16.1	29.9	44.7	67	33.5	48.8	59.5	111	21.5	30.5	41.1
27 May - 02 Jun	650	16.3	21.7	27.6	243	23.5	34.8	50.0	34	41.8	54.6	71.7	68	27.7	36.2	43.9

	LGR to BON (km/day)			
Date at LGR	N	20%	Med.	80%
08 Apr - 14 Apr	14	16.3	24.5	30.2
15 Apr - 21 Apr	269	21.4	33.8	48.1
22 Apr - 28 Apr	386	23.2	34.0	48.0
29 Apr - 05 May	537	25.0	35.1	46.3
06 May - 12 May	462	28.8	38.0	46.5
13 May - 19 May	366	31.4	43.7	57.0
20 May - 26 May	114	38.4	46.4	55.2
27 May - 02 Jun	63	39.4	51.6	61.4

Table 11. Travel time statistics for yearling chinook salmon (hatchery and wild combined) detected and returned to the tailrace of Lower Granite Dam in 1997. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; BON-Bonneville Dam; N-Number of fish on which statistics are based; Med.-Median.

	LGR to LGO (days)				LGO to LMO (days)				LMO to MCN (days)				LGR to MCN (days)			
Date at LGR	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%
06 Apr - 12 Apr	79	6.4	8.1	9.8	34	2.0	2.5	3.5	15	2.7	3.4	4.2	36	11.1	13.4	14.8
13 Apr - 19 Apr	237	4.7	6.1	8.5	66	1.1	1.7	2.1	12	2.4	3.0	4.4	50	9.2	10.6	14.6
20 Apr - 26 Apr	444	4.0	5.8	8.9	146	1.2	1.7	2.5	68	2.5	3.3	4.7	186	9.2	11.7	16.6
27 Apr - 03 May	673	4.2	6.2	8.7	234	1.6	2.0	2.7	75	2.7	3.1	4.2	196	8.6	10.6	13.3
04 May -10 May	495	4.0	5.3	7.4	123	1.2	1.6	2.2	27	2.0	2.4	4.0	107	7.4	9.7	11.5
11 May - 17 May	579	3.1	3.8	5.1	95	1.0	1.4	2.1	16	1.9	2.2	3.6	91	6.2	7.3	9.2
18 May - 24 May	171	3.7	4.6	6.1	54	1.5	2.0	3.0	11	2.6	2.7	5.9	33	7.8	9.1	11.4
25 May - 31 May	44	3.8	4.8	7.6	11	0.8	1.9	2.6	4	2.2	3.0	2.9	8	7.8	9.0	10.8

	LGR to BON (days)			
Date at LGR	N	20%	Med.	80%
08 Apr - 14 Apr	7	17.5	18.3	21.5
15 Apr - 21 Apr	15	14.6	16.7	24.6
22 Apr - 28 Apr	48	13.2	16.5	21.3
29 Apr - 05 May	40	13.1	14.6	17.5
06 May - 12 May	30	12.0	14.7	17.4
13 May - 19 May	61	9.4	10.8	12.1
20 May - 26 May	16	11.1	12.1	14.3
27 May - 02 Jun	4	7.8	10.7	16.6

Table 12. Migration rate statistics for yearling chinook salmon (hatchery and wild combined) detected and returned to the tailrace of Lower Granite Dam in 1997. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam; BON-Bonneville Dam; N-Number of fish on which statistics are based; Med.-Median.

	LGR to LGO (km/day)				LGO to LMO (km/day)				LMO to MCN (km/day)				LGR to MCN (km/day)			
Date at LGR	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%	N	20%	Med.	80%
06 Apr - 12 Apr	79	6.1	7.4	9.4	34	13.2	18.5	23.6	15	28.3	35.5	44.6	36	15.2	16.8	20.3
13 Apr - 19 Apr	237	7.0	9.8	12.8	66	21.6	27.5	40.7	12	26.8	39.8	49.6	50	15.4	21.3	24.4
20 Apr - 26 Apr	444	6.8	10.4	15.2	146	18.5	27.1	37.4	68	25.5	36.4	48.6	186	13.6	19.2	24.5
27 Apr - 03 May	673	6.9	9.7	14.3	234	16.8	22.7	29.5	75	28.3	37.9	44.9	196	16.9	21.2	26.1
04 May -10 May	495	8.1	11.2	14.9	123	21.0	28.0	37.4	27	30.1	49.2	59.2	107	19.6	23.3	30.4
11 May - 17 May	579	11.8	15.8	19.4	95	22.1	32.4	44.2	16	32.8	53.4	63.0	91	24.5	31.0	36.2
18 May - 24 May	171	9.9	13.0	16.3	54	15.3	22.7	30.1	11	20.2	43.4	46.3	33	19.8	24.8	28.7
25 May - 31 May	44	7.9	12.6	15.9	11	18.0	24.6	55.4	4	40.5	40.2	54.8	8	20.8	24.9	28.9

	LGR to BON (days)			
Date at LGR	N	20%	Med.	80%
08 Apr - 14 Apr	7	21.4	25.2	26.3
15 Apr - 21 Apr	15	18.7	27.6	31.7
22 Apr - 28 Apr	48	21.6	27.9	35.0
29 Apr - 05 May	40	26.3	31.6	35.3
06 May - 12 May	30	26.5	31.4	38.6
13 May - 19 May	61	38.1	42.8	49.2
20 May - 26 May	16	32.4	38.0	41.7
27 May - 02 Jun	4	27.8	43.0	58.8

were generally lower in 1997 than in past years. Over the years of the study, a consistent inverse relationship has existed between the migration distance from the release site to Lower Granite Dam and the estimated survival through that reach (Fig. 2). For 1993-1997 estimates, the negative linear correlation between migration distance and estimated survival is significant (R^2 = 66.7%, $P<0.0001$).

For both yearling chinook salmon and steelhead, survival from Lower Granite Dam tailrace to Little Goose Dam tailrace was higher in 1997 than in previous years (survival estimates for previous years were recalculated in the 1996 annual report [Smith et al. 1998]) (Fig. 3). From Little Goose Dam to Lower Monumental Dam, survival in 1997 was lower. For yearling chinook salmon, survival from Lower Monumental Dam to McNary Dam in 1997 was similar to 1995 and higher than in 1996.

DISCUSSION

Results of the 1997 NMFS/UW survival study generally satisfied the research objectives: 1) to estimate reach and project survival in the Snake River throughout the yearling chinook and steelhead migrations, and 2) to evaluate the performance of the survival-estimation models under prevailing operational and environmental conditions in the Snake River.

Survival estimates throughout the 5 years of this study have generally been higher than estimates of survival made in the 1970s, using less sophisticated methods, and in a river system substantially different from today’s (Williams and Matthews 1995). Management strategies should not rely on outdated system survival estimates. Knowledge of the magnitude, locations, and causes of smolt mortality under present passage conditions and under conditions projected for the future is essential to develop strategies for optimizing smolt survival during migration.

Accurate and precise estimates of system survival from upstream release sites in the Snake River Basin to the tailraces of Lower Granite, Little Goose, or Lower Monumental Dams are possible using the SR, Modified Single Release (MSR), and Paired Release (PR) methodologies with the PIT-tag diversion systems in place and with sufficient release numbers. These methodologies should also be used to extend survival estimates over a larger stretch of river once PIT-tag detectors are installed at additional downstream dams. This will permit further exploration of the relationships among smolt survival, smolt travel time, smolt quality, and environmental conditions encountered during migration. (Such investigations will be published elsewhere.) Moreover, the data collected in the first 5 years of this study provide valuable baseline information for evaluation of future management strategies.

CONCLUSIONS

1) Precise survival estimates were obtained for steelhead (hatchery and wild combined) from Lower Granite Dam to the tailraces of Little Goose, Lower Monumental, and McNary Dams. Estimated survival was 97% from the tailrace of Lower Granite Dam to the tailrace of

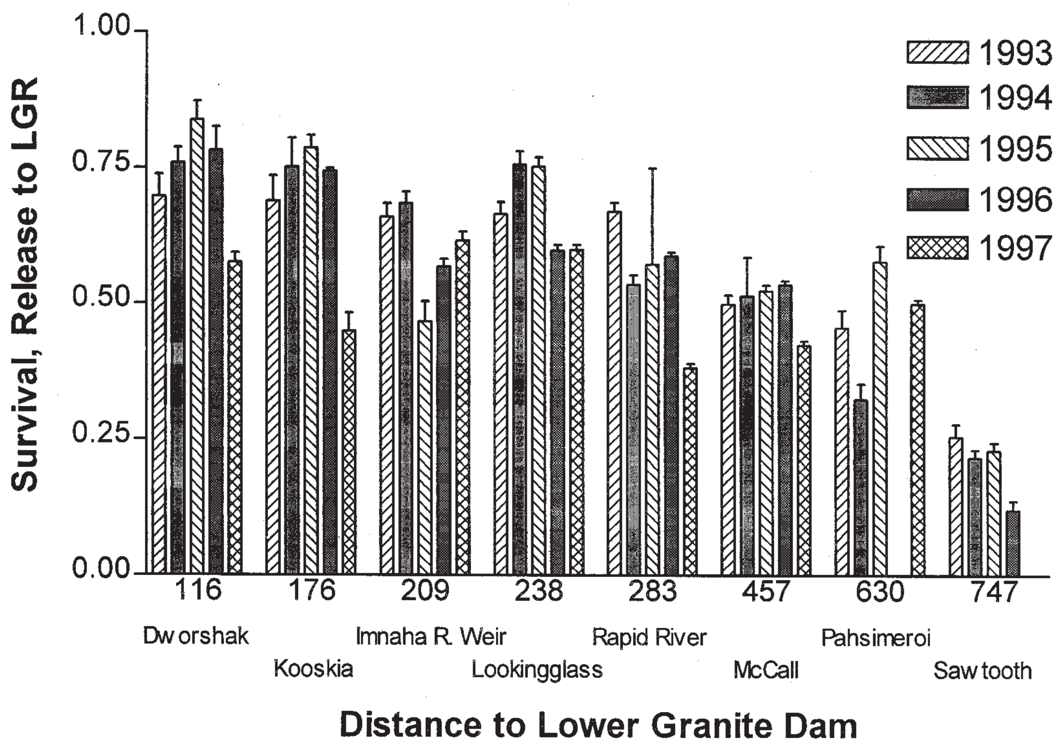

Figure 2. Estimated survival probability from release to Lower Granite Dam tailrace (LGR) for yearling chinook salmon released from Snake River Basin hatcheries, 1993-1997. Distance from release to Lower Granite Dam (km) and standard errors are also shown.

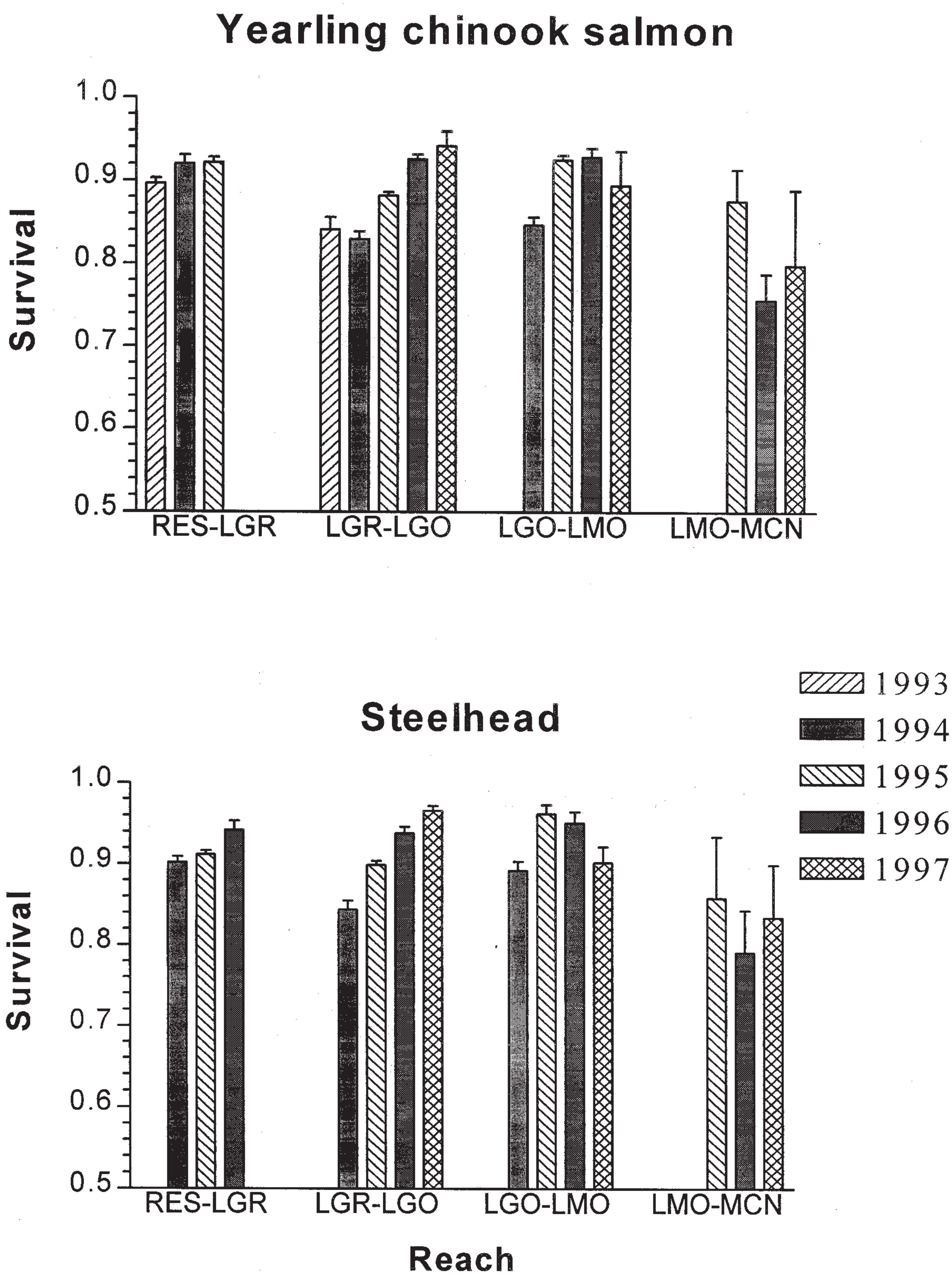

Figure 3. Annual average survival estimates for PIT-tagged salmonids through various reaches, 1993-1997. Standard errors are also shown. Abbreviations: Res-Near head of Lower Granite Reservoir; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Little Goose Dam, 90% from Little Goose Dam tailrace to Lower Monumental Dam tailrace, and 84% from Lower Monumental Dam tailrace to McNary Dam tailrace.

2) Precise survival estimates were obtained for yearling chinook salmon (hatchery and wild combined) from their release points (hatcheries and traps) to Lower Granite Dam, and from Lower Granite Dam to the tailraces of Little Goose, Lower Monumental, and McNary Dams. For yearling chinook salmon released from the tailrace of Lower Granite Dam, estimated survival was 96% from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, 90% from Little Goose Dam tailrace to Lower Monumental Dam tailrace, and 83% from Lower Monumental Dam tailrace to McNary Dam tailrace.

3) It was not possible to estimate survival probabilities to John Day Dam tailrace in 1997, because insufficient numbers of PIT-tagged fish were detected at John Day and Bonneville Dams.

4) Survival and travel time data collected during this study can be used as baseline data for evaluation of future reservoir drawdowns or other management strategies.

RECOMMENDATIONS

Successful validation of field and statistical methodologies in 1997 formed the basis for the following recommendations for 1998 and future years:

1) The SR (MSR when appropriate) and PR methodologies should be adopted for survival estimation. Future protocols should be designed to evaluate the effects of seasonal and environmental variation, differing capture and release protocols, expanded study areas, and additional salmonid stocks.

2) Hatcheries should be provided with minimum release-size requirements for their PIT-tag studies so that survival estimates from hatcheries to detection sites at dams can be made with known precision.

3) Future survival studies should be coordinated with other projects to maximize the data-collection effort and minimize study effects on salmonid resources.

4) Improved statistical precision should be accomplished by maximizing the return of PIT-tagged juveniles to the river through increased detector and diverter efficiency.

5) To date, little mortality has been found in Lower Granite and other reservoirs investigated. Estimates of survival from hatcheries to Lower Granite Dam indicate that substantial mortality occurs upstream from the Snake and Clearwater River confluence area. Efforts should continue to identify where this mortality occurs.

6) Increasing the number of detection facilities in the Columbia River Basin will improve

survival investigations. We recommend installation of detectors and diversion systems at The Dalles, Bonneville, and Priest Rapids Dams. The development of flat plate detector technology in bypass systems would greatly enhance survival estimation capabilities.

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Part 2

Determining Areas of Loss and Delay for Juvenile Hatchery Salmonids above Lower Granite Dam Reservoir, 1997

INTRODUCTION

From 1993 through 1996, the National Marine Fisheries Service (NMFS) and the University of Washington (UW) estimated survival of hatchery-reared yearling chinook salmon through hydroelectric projects and reservoirs in the Snake River using passive integrated transponder (PIT) tags (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998). Using the Single-Release and Paired-Release Models (Smith et al. 1994), these investigators calculated survival estimates for hatchery-reared yearling chinook salmon from near the head of Lower Granite Dam Reservoir to the Lower Monumental Dam tailrace. Results indicated that little mortality occurred in the reservoirs, with most of the mortality associated with dam passage. Survival estimates were also calculated for PIT-tagged yearling chinook salmon from release at or near hatcheries in the Snake River Basin to Lower Granite Dam tailrace (Fig. 2). Combined with estimates from the head of Lower Granite Reservoir, these estimates indicated that most mortality for yearling chinook salmon released from hatcheries occurred in free-flowing reaches above the head of Lower Granite Reservoir (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998).

Approximately 90% of the yearling chinook salmon arriving at Lower Granite Dam are produced in seven hatcheries in Idaho and one in Oregon (Miller et al. 1990), with a total production capacity of about 12 million smolts. Hatchery production increased steadily during the 1980s and may continue to increase (Bowles and Leitzinger 1991), although production was much lower in 1997. Hatchery stocks may play an important role in the recovery of threatened or endangered species, and knowledge of when, where, and why mortality occurs during migration will be needed.

Recent advances in radio telemetry techniques include miniaturization of electronic components. This has led to reduced transmitter size which makes them suitable for implantation in juvenile salmonids. During spring 1997, we used radio telemetry to determine where losses of hatchery yearling chinook salmon occurred between release from Lookingglass Hatchery and the Snake River trap at the head of Lower Granite Reservoir. By determining where losses occur, it may be possible to determine the cause of mortality. Results of this research may provide direction for improving the survival of hatchery chinook salmon produced above Lower Granite Dam and possibly elsewhere in the Columbia River Basin. Efforts to rebuild spring/summer chinook salmon stocks in the Snake River Basin will have a greater chance of success after the locations and causes of mortality to juveniles are identified and addressed. In addition, information from this study may be useful to other researchers conducting telemetry studies on juvenile fish.

Research objectives were to 1) determine where losses to the hatchery population occur, calculate travel times, and collect information on dispersal and migration behavior for hatchery-reared yearling chinook salmon above Lower Granite Reservoir, 2) compare travel times, survival estimates, and growth of hatchery-reared yearling chinook salmon with surgically implanted radio/sham tags to those with PIT tags to evaluate relative effects of the tags on fish performance.

METHODS

Study Area

The study area extended from Lookingglass Hatchery downstream to Bonneville Dam on the Columbia River and was separated into two sections. The first section extended from Lookingglass Hatchery downstream to the Snake River smolt monitoring trap at the head of Lower Granite Reservoir (Fig. 4). In this section, we collected data using radio telemetry. The telemetry portion of the study area did not include Lower Granite Reservoir because migrational characteristics of hatchery yearling chinook salmon from the head of Lower Granite Reservoir downstream to Lower Granite Dam were previously investigated using radio telemetry by the National Biological Service in 1994 and 1995 (Rondorf and Banach 1996). The second section extended from the Snake River smolt monitoring trap at the head of Lower Granite Reservoir downstream to the tailrace of Bonneville Dam. In this section, we collected data from PIT-tag detection facilities at Lower Granite, Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams. As a pilot study to validate the methodology, fish were radio-tagged at only one hatchery in 1997. If the method is proven valid, additional hatcheries and other species or rearing types may be included in future years.

Experimental Fish

Fish used in this study were yearling spring/summer chinook salmon of Rapid River stock reared at Lookingglass Hatchery and released into the Grande Ronde River drainage. Lookingglass Hatchery was selected on the basis of the availability of yearling chinook salmon, distance to Lower Granite Dam (middle range for hatcheries in the Snake River Basin), accessibility of the study area, and relatively low historical survival estimates between release and Lower Granite Dam tailrace (i.e., we expected sufficient mortality to validate the methods).

Radio Tags and Tagging Protocol

From 10-14 March, we surgically implanted a combination radio transmitter/PIT tag into 129 yearling Lookingglass Hatchery chinook salmon. An additional 470 yearling chinook salmon were implanted with a combination sham radio transmitter/PIT tag to supplement the sample size of “radio-tagged” fish for analysis of the effects of surgically implanted radio transmitters on growth, travel time, and survival. Surgery was performed at least 20 days prior to release to allow fish to recover fully from the procedure and become acclimated to the presence of the tags prior to release. Surgical techniques were similar to those described by Hart and Summerfelt (1975), Mellas and Haynes (1985), Ross (1982), and Moore et al. (1990). After surgery, radio-tagged fish were segregated from the general hatchery population for 5 days to allow post-surgical recovery and facilitate the removal of post-surgical mortalities. Following the 5-day post-surgical holding period, radio-tagged fish were distributed among the general hatchery population. All tagged fish were released with the general hatchery population on 7 April.

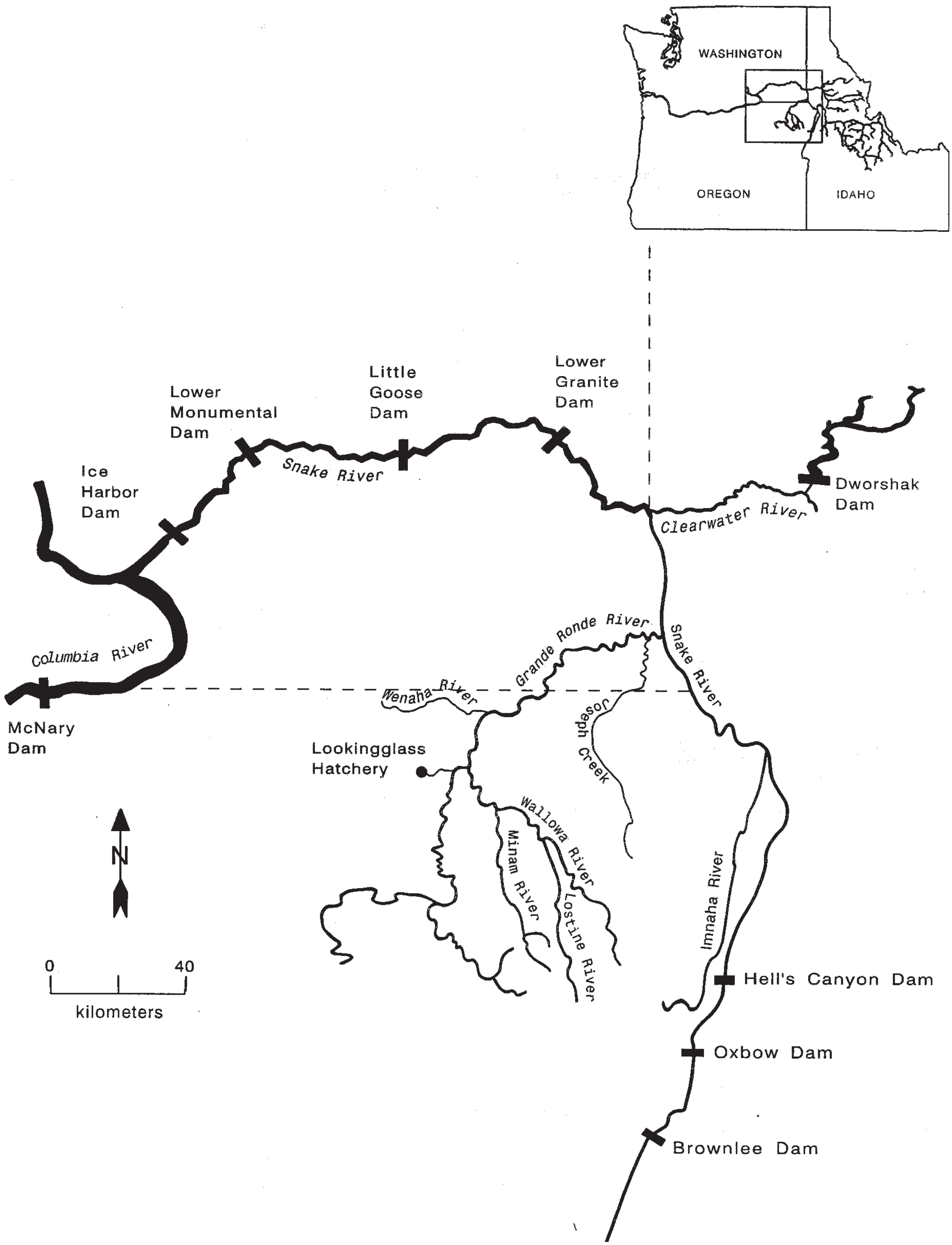

Figure 4. Study area showing the location of Lookingglass Hatchery and hydroelectric dams on the lower and middle Snake River.

We purchased radio transmitters for the study from Advanced Telemetry Systems, Inc.[2] Each tag had a pulse-coded delay, measured 18 mm in length by 7 mm in diameter, and weighed 1.9 g in air. The sham radio transmitter tags were identical to the functional radio transmitters in size and weight. A PIT tag was embedded in the radio- or sham-tag epoxy potting by the radio tag manufacturer. Each functional radio tag had a unique identification code transmitted with each pulse (base pulse rate of 4 seconds). To extend tag life, signal transmission was delayed until 20 days after tag implantation. We used transmission-delay tags because available technology did not provide sufficiently small radio tags capable of continuous transmission from hatchery tagging throughout the smolt migration. When activated, transmitters operated for 2 hours and then shut down for 20 days to conserve battery life. The tags restarted continuous transmission just prior to release from the hatchery. Tag life extended 45 days after continuous transmission began (Table 13). This schedule provided transmitting radio tags within the hatchery population throughout the entire migration period within the telemetry section of the study area. Winter (1983) recommended that radio transmitter weight be 2% or less of the fish's weight. However, Adams et al. (1998) demonstrated that the growth, feeding behavior, and survival of juvenile chinook salmon were unaffected by surgically implanted radio transmitters that weighed up to 5.5% of the fish's weight. Our transmitters weighed 1.9 g, or an average of 6.7% of the fish's weight (range 4.3 to 8.3%). Although radio transmitters have decreased in both size and weight in recent years, tag life requirements for this study precluded use of smaller tags.

Monitoring Radio-Tagged Fish

Between the hatchery release location and the head of Lower Granite Reservoir a total of 12 fixed-site telemetry receivers (manufactured by NMFS) were positioned downstream from major tributary confluences or at locations above areas of limited access (Table 14). Distance between monitoring sites was 35 km or less. Receivers at the upper and lower ends of the study area were closer together than those in the middle of the study area, because we anticipated the highest mortality in these areas. Telemetry receivers were powered by 120 V AC where available, and by solar energy with battery backup in remote areas. We downloaded receiver data once or twice weekly, depending on accessibility. Continuous operation of each fixed-site receiver was verified by the presence of a stationary test tag within the monitoring area of the receiver. Test tags transmitted for 10 seconds every hour for the duration of the study. Absence of records from test tags indicated periods when fixed-site receivers were not operating. Telemetry data from fixed-site receivers was checked and cleaned of data anomalies by eliminating records with less than a 4-second-pulse rate, records with less than two observations, and by eliminating records of codes that were known not to be within the release population. Records of PIT-tag detections at dams supplemented final location data for radio-tagged fish.

Losses within the radio-tagged population were determined from fish that were detected by one receiver then failed to pass the next fixed-site receiver downstream (prior to expiration of the transmitter battery) and by mobile tracking to pinpoint the exact location of stationary individuals. Mobile tracking was conducted between fixed-site receivers at least once per week

[2] Reference to trade names does not imply endorsement by National Marine Fisheries Service.

Table 13. Tagging schedule, radio transmitter operation schedule, and delay protocol for the scheduled hatchery release on 7 April 1997.

Date of tagging	Days until Release	Number of fish tagged	Tag transmission delay	Tag transmission start date	Tag transmission end date	Expected tag life (days)
Combination sham radio transmitter/PIT tag						
10 March	28	65				
11 March	27	120				
13 March	25	155				
14 March	24	130				
Combination radio transmitter/PIT tag						
12 March	26	129	20	1 April	15 May	45
Total		599				

Table 14. Fixed-site radio telemetry monitoring locations for Lookingglass Hatchery yearling chinook salmon released in Lookingglass Creek, 1997.

Distance from hatchery (km)	Distance from previous receiver (km)	Receiver number	Location description
0	0		release location
3.1	3.1	1	mouth of Lookingglass Creek
27.6	24.5	2	below Martins Misery Rapids, Grande Ronde River
62.4	34.8	3	between Mud Creek and Troy, OR, Grande Ronde River
73.3	10.9	4	near the OR/WA state borders, Grande Ronde River
97.9	24.6	5	mouth of Rattlesnake Creek, Grande Ronde River
114.3	16.4	6	mouth of Shumaker Creek, Grande Ronde River
135.5	21.2	7	Grande Ronde River smolt monitoring trap, Grande Ronde River
141.1	5.6	8	confluence of Grande Ronde and Snake Rivers
155.8	14.7	9	mouth of Couse Creek, Snake River
180.6	24.8	10	upstream end of Hells Gate State Park, Snake River
181.7	1.1	11	downstream end of Hells Gate State Park, Snake River
187.0	5.3	12	Snake River smolt monitoring trap near Clarkston, WA, Snake River

by vehicle or boat. Mortalities were further confirmed by attempting to disturb radio-tagged fish that had remained stationary since the previous mobile tracking survey.

A portion of radio-tagged and PIT-tagged fish from Lookingglass Hatchery that arrived at Little Goose Dam was collected by the PIT-tag separation-by-code system at the dam, examined, measured, weighed, and compared to determine the effect of the radio tag on growth. The separation-by-code system was programmed to collect a maximum of 100 fish with each type of tag.

Data Analysis

To evaluate the effect of the radio tag on fish performance, we estimated and compared survival probabilities from release to Lower Granite Dam tailrace using the Single-Release Model (Iwamoto et al. 1994, Smith et al. 1994) for the radio/sham-tagged and PIT-tagged-only groups. For this comparison, the radio- and sham-radio-tagged fish were analyzed as a single group, as only PIT-tag detections (no radio detections) were required to estimate survival probabilities to Lower Granite Dam and downstream. The number of fish per release group was calculated to maximize the ability to detect a difference in survival, given constraints imposed by the logistics of radio tagging. The release of approximately 600 fish in each group allowed a high probability (about 62%) of detecting a significant difference ($\alpha = 0.05$) in survival to Lower Granite Dam, if detection rates were similar to previous years and the difference in survival between the two groups was 10% or greater. Median travel times for defined sections of the study area were also calculated and compared.

We estimated survival of radio-tagged yearling chinook salmon between the hatchery and points above Lower Granite Dam Reservoir using the Single-Release Model (Iwamoto et al. 1994, Smith et al. 1994) and data from sequential fixed-site radio telemetry receivers to construct "detection histories" for radio-tagged fish. Detections at receiver sites 1, 8, 10, and 12 (Table 14) were used in the capture histories, from which we estimated survival probabilities for the following river reaches: Lookingglass Creek (release to monitoring site 1); the Grande Ronde River (monitoring sites 1 to 8); the free-flowing reach of the Snake River (monitoring sites 8 to 10); and the transition area of the Snake River where the river changes from free-flowing to Lower Granite Reservoir (monitoring sites 10 to 12). For survival estimates based on radio detections we used only fish that were detected by radio at least once by fixed-site monitors, omitting from the analysis radio-tagged fish that were detected only by PIT-tag detectors at dams and those that were never detected at all. The detection history for each fish included a digit for each of the four receiver sites, followed by a single digit indicating whether the fish was detected by PIT-tag detectors at one or more downstream dam. Fish that were lost (radio failure) between two fixed-site receivers were considered "known removals" at the last receiver site at which they were detected. If causes of lost radio signals were related to mortality events (e.g., an avian predator removing the tag from mobile receiver range), then treating lost signals as known removals will result in an overestimate of the true survival probability. Treating lost signals as known removals implies the assumption that signal loss is unrelated to mortality. One fish was not detected by any fixed-site receiver, but was confirmed dead by mobile tracking below receiver site 2. Because this fish had a working radio and we knew it had passed receiver site 1, we changed its capture history at site 1 from “0" to “1" for the analysis.

RESULTS

Tagging and Release Protocols

A total of 599 hatchery yearling chinook salmon were surgically tagged with either a combination radio transmitter/PIT tag or a combination sham radio transmitter/PIT tag at Lookingglass Hatchery from 10 to 14 March (Table 15). Fish for Lookingglass Hatchery yearling chinook salmon production(Rapid River stock) were reared in four raceways and we attempted to evenly distribute our tagged fish across them (Table 15). Mean fork length (mm), weight (g), and condition factor (*K*) for surgically tagged fish were 135, 28.5, and 1.16, respectively (Table 16). Mortality from tagging until release (24 to 28 days) for surgically tagged fish was 37.6% (Table 15). Two mortalities during this time appeared to be the result of predation by a belted kingfisher (*Megaceryle alcyon*). Six days after tagging, daily mortality decreased substantially (Fig. 5). However, 9 days after tagging, daily mortality increased rapidly, peaking 15 days after tagging, possibly due to disease aggravated by stress associated with surgery
.

Oregon Department of Fish Wildlife (ODFW) hatchery personnel PIT tagged 41,819 yearling chinook salmon at Lookingglass Hatchery from 3 to 13 February. Mean fork length (mm), weight (g), and *K* for PIT-tagged fish were 120.4, 20.0, and 1.12, respectively (Table 17). Mortality between tagging and release (53 to 63 days) was 4.8% for PIT-tagged fish (P. Sankovich, ODFW, pers. commun., February 1998).

At 1600 hours on 7 April, a total of 374 surgically tagged fish (88 radio-tagged and 286 sham-tagged) were released with the Lookingglass Hatchery production release of 156,600 yearling chinook salmon. The production release included 39,825 PIT-tagged yearling chinook salmon. Release began with a volitional period, followed by a forced release facilitated by crowding and dewatering the raceways after 24 hours. Very few fish exited the hatchery raceways during the volitional period.

Travel Time and Migrational Characteristics

Of 88 radio-tagged fish released from the hatchery, 61 (69.3%) were subsequently detected by either fixed-site telemetry receivers or mobile tracking (Table 18). Twenty-two radio-tagged fish (25.0%) were never detected by either telemetry receivers or PIT-tag detectors. Five radio-tagged fish (5.7% of those released from the hatchery) were detected by PIT-tag detectors at hydroelectric dams or smolt monitoring traps, but were never detected at fixed-site telemetry receivers or located during mobile tracking, also indicating radio tag failure. In addition, 10 radio-tagged fish (11.4%) were detected at least once and then lost within the study area because of battery failure. Water leakage caused several transmitters recovered from mortalities to fail. Based on these results, we estimate that between 30.7% and 42.1% of the

Table 15. Number tagged, tagging mortality, and number released of surgically tagged Lookingglass Hatchery yearling chinook salmon by raceway, 1997.

	Number tagged			Tagging mortality				Number released		
Raceway	Sham	Radio	Total	Sham	Radio	Total	Percent	Sham	Radio	Total
14	115	30	145	41	3	44	30.3	74	27	101
15	120	30	150	33	10	43	28.7	87	20	107
16	120	36	156	57	13	70	44.9	63	23	86
17	115	33	148	53	15	68	45.9	62	18	80
Total	470	129	599	184	41	225	37.6	286	88	374

Table 16. Length, weight, and condition factor (*K*) at tagging for radio/PIT-tagged (10-14 March) yearling chinook salmon at Lookingglass Hatchery, 1997. Abbreviations: Min-minimum, Max-maximum, Ave-Mean.

	Fork length (mm)				Weight (g)				*K*			
Raceway	N	Min	Max	Ave	N	Min	Max	Ave	N	Min	Max	Ave
14	145	126	159	134.8	145	22.9	43.7	28.0	145	0.96	1.35	1.14
15	150	129	150	134.5	149	23.0	39.8	28.5	149	0.98	1.35	1.17
16	156	130	150	135.4	155	23.3	42.5	28.7	155	0.90	1.35	1.15
17	148	130	152	135.2	148	23.4	41.1	28.6	148	1.01	1.32	1.16
Overall	599	126	159	135.0	597	22.9	43.7	28.5	597	0.90	1.35	1.16

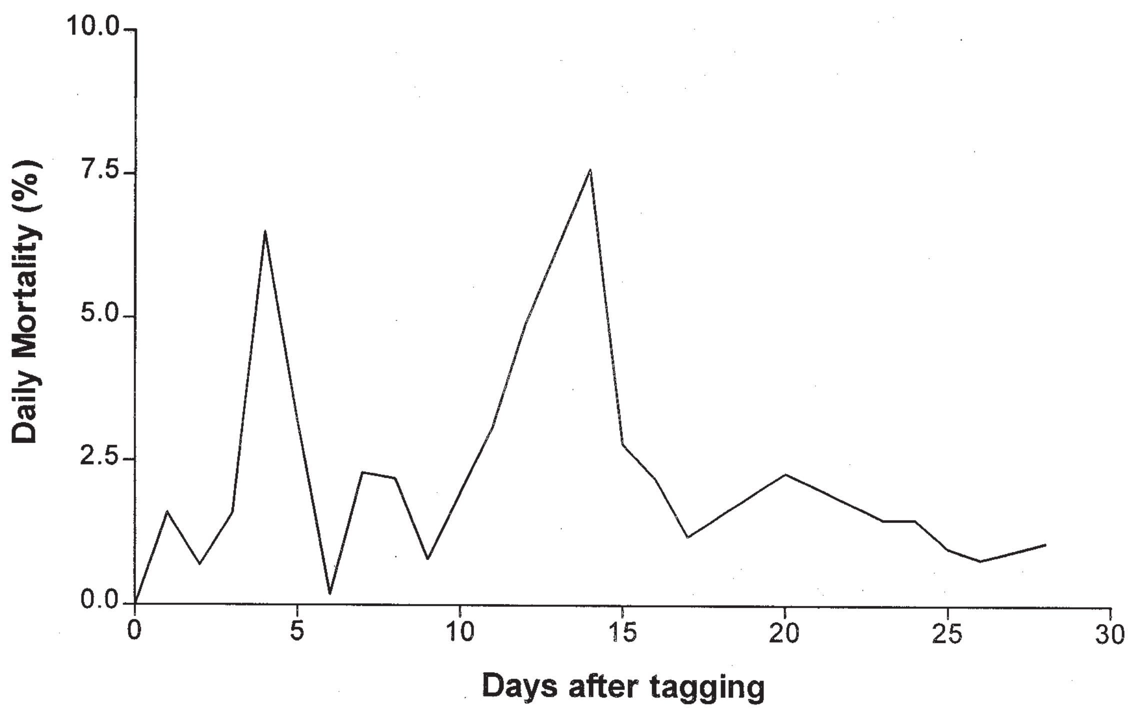

Figure 5. Daily percent mortality between surgery and release of radio/sham-tagged Lookingglass Hatchery yearling chinook salmon, 1997.

Table 17. Length, weight, and condition factor (*K*) at tagging for PIT-tagged (3-13 February) yearling chinook salmon at Lookingglass Hatchery, 1997. Abbreviations: Min-minimum, Max-maximum, Ave-Mean.

	Fork length (mm)				Weight (g)				*K*			
Raceway	N	Min	Max	Ave	N	Min	Max	Ave	N	Min	Max	Ave
14	10,435	82	277	119.5	101	13.6	32.4	20.2	101	0.91	1.28	1.10
15	10,422	62	287	118.0	100	9.4	28.4	19.0	100	0.63	1.31	1.07
16	10,443	73	286	119.6	99	14.0	30.6	20.0	99	0.69	1.35	1.13
17	10,480	83	176	122.9	102	7.1	44.6	20.7	102	0.91	1.32	1.16
Overall	41,780	62	287	120.4	402	7.1	44.6	20.0	402	0.63	1.35	1.12

Table 18. Summary of final disposition of Lookingglass Hatchery radio/PIT-tagged yearling chinook salmon, 1997.

	Number of fish		Percent
Total released	88		
Never detected (radio tag failure)	22 of 88		25.0
Detected only by PIT (radio tag failure)	5 of 88		5.7
Radio detected at least once	61 of 88		69.3
Observed exiting study area (detected by monitor 12)	32 of 61		52.5
Overall lost within the study area (tag failure following at least one radio detection)	10 of 61		16.4
lost in Lookingglass Creek		0 of 61	0.0
lost in the Grande Ronde River		8 of 61	13.1
lost in the Snake River		2 of 61	3.3
Overall observed migration mortality	19 of 61		31.1
mortality in Lookingglass Creek (0.1-2.0 km downstream from Lookingglass Hatchery)		10 of 61	16.4
mortality in the Grande Ronde River (46.2-113.8 km downstream from Lookingglass Hatchery)		3 of 61	4.9
mortality in the Snake River (141.3-164.6 km downstream from Lookingglass Hatchery)		6 of 61	9.8

radio transmitters released from the hatchery malfunctioned or failed due to water leakage. Testing by the manufacturer indicated that the two-part epoxy potting material was incorrectly mixed and therefore did not cure properly. The high rate of radio transmitter failure significantly reduced the quantity of data collected during this study. Therefore, analysis within the telemetry section of the study area was based on a release group of only 61 fish.

Fifty-one (83.6%) of the 61 radio-tagged fish released from the hatchery were located downstream from fixed-site monitoring station 1 at the mouth of Lookingglass Creek (3 km downstream from Lookingglass Hatchery) (Table 18). Of these, 42 were logged as they passed the first fixed-site monitoring station. Only 7 radio-tagged fish migrated out of Lookingglass Creek during the volitional release period, while 35 fish migrated out of the creek after the volitional period. Twenty-four hours after the forced release, 20 radio-tagged fish remained either within or near the hatchery release pipe, along with numerous additional hatchery fish. Of these 20 radio-tagged fish, 10 left the area and migrated out of Lookingglass Creek between 30 and 297 hours (median 76 hours) after the forced release. Radio tags expired for the remaining 10 radio-tagged fish before they left the release area. These 10 fish were assumed to have died in Lookingglass Creek.

Migration out of Lookingglass Creek into the Grande Ronde River (migration past Site 1) occurred between 7 and 21 April with median date 8 April (n = 42) (Fig. 6). Migration out of the Grande Ronde River and into the Snake River (migration past Site 8) occurred from 9 April through 14 April, with median date 9 April (n = 26).

Of 61 radio-tagged fish located after release from the hatchery, 32 (52.5%) passed monitoring Site 12 at the downstream end of the telemetry study area near the Snake River smolt monitoring trap at Clarkston, WA (187 km downstream from the Lookingglass Hatchery). Migration out of the telemetry portion of the study area occurred from 10 April through 2 May, with median date 17 April (n = 27) (Fig. 6).

Migration rates for individual radio-tagged hatchery yearling chinook salmon through the entire telemetry portion of the study area (187 km) ranged from 0.32 to 3.16 km/hr, with median of 0.8 km/hr (hatchery release to Site 12) (Table 19). Median migration rate from the hatchery to the mouth of Lookingglass Creek (release to Site 1) was 0.11 km/hr. Migration rates increased substantially after the fish entered the Grande Ronde River and remained high until they entered the Snake River (between Sites 1 and 9). After Snake River entry, downstream migration rates decreased substantially (between monitoring Sites 9 and 12) (Table 19). The median migration rate from Lookingglass Hatchery to Lower Granite Dam was 17.4 km/day (0.73 km/hr) for radio-tagged fish (Table 20) and 11.7 km/day (0.49 km/hr) for PIT-tagged fish (Table 21).

Mortality During Migration

A total of 19 mortalities were confirmed for radio-tagged fish between Lookingglass Hatchery and the Snake River smolt monitoring trap at the head of Lower Granite Dam Reservoir (Table 18). The majority of the mortalities occurred in Lookingglass Creek near the

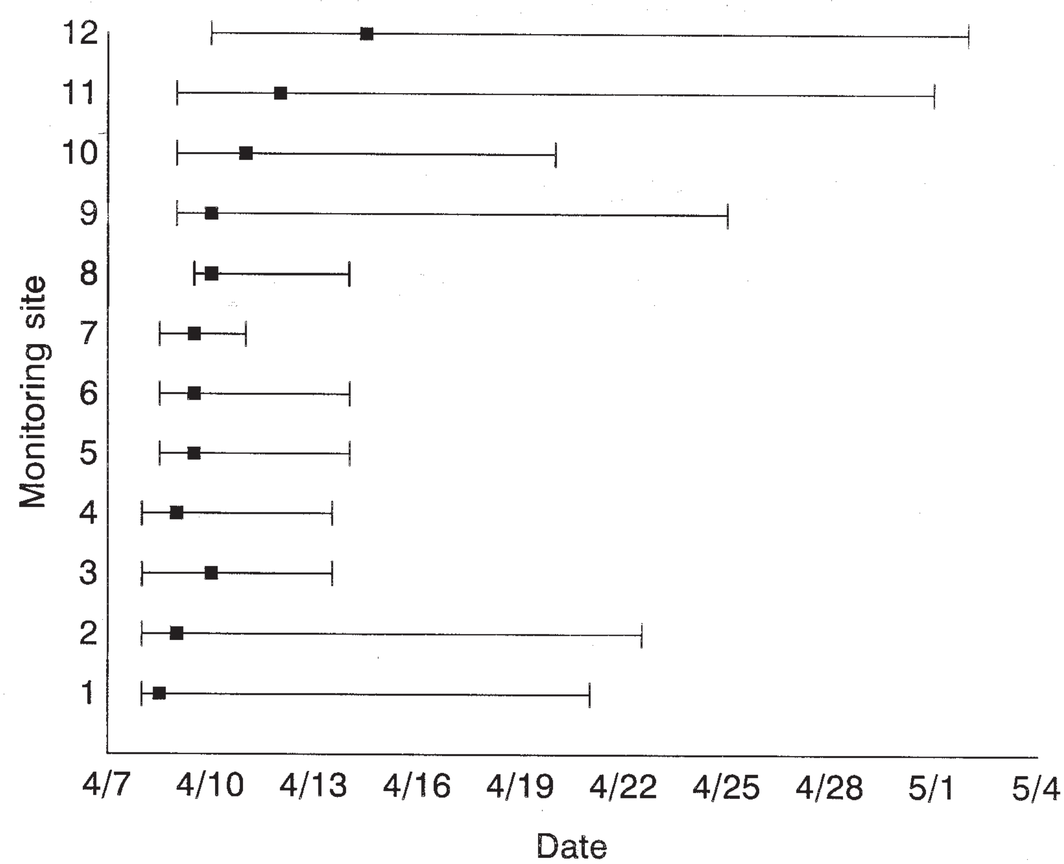

Figure 6. Range and median of migration dates past fixed-site telemetry receivers for radio-tagged Lookingglass Hatchery yearling chinook salmon, 1997.

Table 19. Travel time and migration rates for radio/PIT-tagged yearling chinook salmon between release at Lookingglass Hatchery and Lower Granite Dam, 1997. Abbreviations: H-Lookingglass Hatchery release location; LGR-Lower Granite Dam tailrace.

			Travel time (hours)					Migration rate (km/hour)				
Detection locations	Distance (km)	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
H to 1	3.1	42	1.1	25.1	27.2	63.8	321.0	0.01	0.05	0.11	0.12	2.78
1 to 2	24.5	32	3.2	3.5	3.8	15.0	238.2	0.10	1.63	6.46	7.01	7.65
2 to 3	34.8	11	4.2	4.6	4.7	5.5	29.1	1.20	6.38	7.36	7.62	8.29
3 to 4	10.9	7	1.3	1.4	1.5	9.4	17.9	0.61	1.16	7.37	7.86	8.19
4 to 5	24.6	16	2.9	3.0	3.1	6.2	16.4	1.50	3.96	7.91	8.20	8.51
5 to 6	16.4	25	1.9	2.0	2.2	2.3	11.2	1.47	7.02	7.45	8.05	8.62
6 to 7	21.2	25	2.6	2.9	3.1	3.4	10.4	2.04	6.27	6.75	7.34	8.26
7 to 8	5.6	21	0.6	0.7	0.8	4.8	11.3	0.50	1.16	7.07	8.48	9.23
8 to 9	14.7	23	1.7	2.1	2.3	9.8	35.1	0.42	1.50	6.36	7.18	8.66
9 to 10	24.8	6	2.6	4.9	36.9	86.0	190.6	0.13	0.29	0.67	5.08	9.39
10 to 11	1.1	20	0.6	0.8	1.0	8.8	219.2	0.01	0.13	1.15	1.45	1.83
11 to 12	5.3	18	0.9	1.8	2.3	15.9	62.3	0.09	0.33	2.33	3.03	5.76
H to 12	187.0	27	59.2	65.4	233.0	324.0	590.9	0.32	0.58	0.80	2.86	3.16
12 to LGR	51.2	7	77.2	92.8	172.3	306.5	338.9	0.15	0.17	0.30	0.55	0.66

Table 20. Travel time and migration rates from release to Lower Granite, Little Goose, and Lower Monumental Dams for surgically-tagged yearling chinook salmon from Lookingglass Hatchery, 1997. Abbreviations: LGR-Lower Granite Dam tailrace; LGO-Little Goose Dam tailrace; LMO-Lower Monumental Dam tailrace; MCN-McNary Dam tailrace.

	Release to LGR	Release to LGO	Release to LMN	Release to MCN
		Travel time (days)		
Number	31	32	19	7
Minimum	6.9	11.1	12.2	21.5
20%	9.0	14.5	17.0	22.6
Median	13.7	19.3	27.1	24.0
80%	17.5	24.2	32.2	29.4
Maximum	39.2	31.4	34.8	32.3
		Migration rate (km/day)		
Number	31	32	19	7
Minimum	6.1	9.5	9.9	10.7
20%	13.6	12.3	10.7	11.7
Median	17.4	15.4	12.7	14.4
80%	26.3	20.6	20.2	15.2
Maximum	34.6	26.8	28.4	16.0

Table 21. Travel time and migration rates from release to Lower Granite, Little Goose, and Lower Monumental Dams for PIT-tagged yearling chinook salmon from Lookingglass Hatchery, 1997. Abbreviations: LGR-Lower Granite Dam tailrace; LGO-Little Goose Dam tailrace; LMO-Lower Monumental Dam tailrace; MCN-McNary Dam tailrace.

	Release to LGR	Release to LGO	Release to LMN	Release to MCN
		Travel time (days)		
Number	7,716	6,249	5,089	2,049
Minimum	3.8	7.9	9.1	12.5
20%	14.6	19.1	23.2	25.2
Median	20.4	25.1	27.2	30.4
80%	26.1	31.1	31.9	34.5
Maximum	64.7	58.9	58.2	57.7
		Migration rate (km/day)		
Number	7,716	6,249	5,089	2,049
Minimum	3.7	5.1	5.9	8.0
20%	9.1	9.6	10.8	13.4
Median	11.7	11.9	12.7	15.3
80%	16.3	15.6	14.8	18.4
Maximum	62.7	37.7	37.9	37.1

hatchery. Of the 10 fish that died in Lookingglass Creek, 3 were apparently taken by river otters (*Lutra canadensis*). Causes of mortality for the remaining seven fish were not determined. We confirmed three mortalities in the Grande Ronde River and six mortalities in the Snake River but could not determine causes for these mortalities. Other than in Lookingglass Creek, the only concentration of mortality occurred in a 23-km section of the Snake River below the confluence of the Grande Ronde River (between fixed telemetry monitoring Sites 8 and 10), which accounted for six of the confirmed mortalities (Table 18).

Telemetry Receiver Efficiency

We estimated fixed-site receiver efficiency from records of fish missed by a particular receiver and then subsequently detected at a fixed-site downstream. Estimated efficiency for fixed-site receivers ranged from 25.0 to 80.8% (Table 22). Receivers at Sites 3 and 4 had reduced efficiency because they malfunctioned for 2 days beginning on the day the fish were released from the hatchery. Potential reasons for missing radio-tagged fish by fixed-site receivers included malfunctioning tags that transmitted intermittently and malfunctioning receivers. In addition to radio-tag detections at fixed-site receivers, 196 fish locations were determined by mobile tracking.

Survival Estimates

Survival estimates for PIT-tagged yearling chinook salmon from Lookingglass Hatchery to the tailrace of Lower Granite Dam (1993 to 1997) have ranged from 59.8 to 75.7% (Fig. 2). The 1997 survival estimate of 59.9% was almost identical to the 1996 survival estimate (the two lowest annual survival estimates between 1993 and 1997). Survival estimates for PIT-tagged Lookingglass Hatchery fish for 1997 in reaches downstream from Lower Granite Dam were similar to estimates from previous years.

Using the Single-Release Model (Iwamoto et al. 1994, Smith et al. 1994) and data from the sequential fixed-site radio telemetry receivers, we calculated additional survival estimates in reaches upstream from Lower Granite Reservoir. Survival estimates for these reaches had relatively large standard errors due to the small number of fish released with functioning radio transmitters. Thus, differences in survival estimates in various reaches are not statistically significant. Nonetheless, survival estimates were lowest in Lookingglass Creek and in the Snake River transition zone (Sites 10 to 12) (Table 23).

Tag Effect Evaluation

A higher proportion of fish marked only with PIT tags than of those surgically tagged with combination radio/sham-PIT tags were detected at dams on the Snake and Columbia Rivers (Table 24). Estimated survival from Lookingglass Hatchery to the tailrace of Lower Granite Dam was significantly lower (likelihood ratio test versus separate SR model for each group: $P = 0.013$) for the radio/sham-tagged group (Table 23). Estimated survival from Lower Granite Dam tailrace to Little Goose Dam tailrace was also significantly lower for the radio/sham-tagged

Table 22. Expected and actual numbers of radio/PIT-tagged fish detected and estimated efficiency of fixed-site telemetry receiver stations. Abbreviations: LGC-Lookingglass Creek; GRR-Grande Ronde River; SR-Snake River.

Site number	RKm from Lookingglass Hatchery	River	Number of fish expected	Number of fish detected	Efficiency (%)
1	3.1	LGC	52	42	80.8
2	27.6	GRR	46	34	73.9
3	62.4	GRR	44	11	25.0
4	73.3	GRR	44	20	45.5
5	97.9	GRR	44	26	59.1
6	114.3	GRR	44	30	68.2
7	135.5	GRR	43	25	58.1
8	141.1	SR	42	27	64.3
9	155.8	SR	40	30	75.0
10	180.6	SR	36	19	52.8
11	181.7	SR	36	24	66.7
12	187.0	SR	35	30	85.7

Table 23. Estimates of survival probabilities and median travel times for PIT-tagged and surgically radio/PIT-tagged yearling chinook salmon released from Lookingglass Hatchery, 1997. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: SNJ-Snake river smolt monitoring trap; LGR-Lower Granite Dam tailrace; LGO-Little Goose Dam tailrace; LMO-Lower Monumental Dam tailrace.

		PIT-tagged		Radio-tagged	
Reach	Length of reach (km)	Estimated survival probability	Median travel time (days)	Estimated survival probability	Median travel time (days)
Lookingglass Creek (release to Site 1)	3.1	NA	NA	0.858 (0.050)[a]	1.1
Grande Ronde River (Site 1 to 8)	138.0	NA	NA	0.911 (0.071)[a]	1.1
Snake River free-flowing (Site 8 to 10)	39.5	NA	NA	0.911 (0.096)[a]	0.5
Snake River transition (Site 10 to 12)	6.4	NA	NA	0.857 (0.106)[a]	0.2
Release to SNJ	187.0	0.638 (0.038)	6.3	0.611 (0.080)[a]	9.7
SNJ to LGR	51.2	0.938 (0.057)	8.6	NA	7.3
Release to LGR	238.2	0.598 (0.010)	20.4	0.307 (0.065)[b]	13.6
LGR to LGO	59.5	0.928 (0.023)	4.8	0.518 (0.132)[b]	5.6
LGO to LMO	46.7	0.835 (0.022)	1.9	NA	1.9
Release to LMO	344.4	0.463 (0.011)	27.2	NA	25.5

[a.] Estimated from radio detections of 61 fish detected at least once by radio.
[b.] Estimated from PIT-tag detections of 374 fish surgically implanted with radio tag or sham radio tag.

Table 24. Numbers and percentages of PIT-tag detections at hydroelectric dams on the Snake and Columbia Rivers for ODFW PIT-tagged and NMFS surgically-tagged Lookingglass Hatchery yearling chinook salmon, 1997.

	ODFW PIT-tagged		NMFS surgically-tagged	
	Number	Percent	Number	Percent
Total released	39,825		374	
Lower Granite Dam	7,716	19.4	31	8.7
Little Goose Dam	6,249	15.7	32	8.5
Lower Monumental Dam	5,089	12.8	19	5.1
McNary Dam	2,049	5.1	7	1.9
Bonneville Dam	690	1.7	2	0.5
Total number unique detections	17,259	43.3	69	18.4

group (likelihood ratio test: $P = 0.028$). Too few radio-tagged fish were detected to estimate their survival to reaches below Little Goose Dam.

Median travel-time estimates were also significantly different (two-sample t-test: $P < 0.001$) between PIT-tagged fish and surgically radio/sham-tagged fish from Lookingglass Hatchery to Lower Granite Dam. Detection distributions at Lower Granite Dam indicated that the radio/sham-tagged fish were poorly represented during the second half of the passage distribution (Fig. 7).

A total of 127 (23 surgically radio/sham-tagged and 104 PIT-tagged) Lookingglass Hatchery yearling chinook salmon were recaptured by the separation-by-code-system at Little Goose Dam and were measured, weighed, and examined. There were insufficient numbers of PIT-tagged fish weighed during tagging and subsequently recaptured at Little Goose Dam to compare growth (as a change in weight or condition factor). The PIT-tagged group was tagged a month earlier than the radio-tagged group; therefore, growth was measured as the increase in fork-length per week as an index of growth. The radio-tagged fish grew at a slower rate (average 0.2 mm/week) than the PIT-tagged fish (average 1.1 mm/week). In addition, 20 (87%) of the 23 surgically radio-tagged fish lost weight (average 3.3 g) between tagging and recapture at Little Goose Dam (40 to 59 days).

DISCUSSION

The primary objective of this study was to provide information on where losses to yearling chinook salmon released from a hatchery occurred upstream from Lower Granite Dam. Applicability of information from radio-tagged fish to the general population depends upon the radio-tagged fish having survival rates and travel times during downstream migration similar to those of the PIT-tagged hatchery population. Because survival estimates and travel times between Lookingglass Hatchery and the tailrace of Lower Granite Dam differed between the two groups, observed migrational characteristics of the radio-tagged fish may not have been representative of the Lookingglass Hatchery population. In addition, radio-tagged fish grew at a lower rate than PIT-tagged fish. Observed significant differences in survival estimates, travel times, and growth rates between radio-tagged and PIT-tagged fish may have implications to other juvenile salmonid telemetry research using similar equipment and methods.

The majority of the hatchery production as well as the radio-tagged fish did not leave the Lookingglass Hatchery raceways volitionally, but had to be physically crowded. Moreover, a significant portion of the population remained near the hatchery and eventually died. Juvenile salmonids that do not actively migrate may not be physiologically ready to migrate (Muir et al. 1994). Those radio-tagged fish that did leave Lookingglass Creek moved rapidly downstream in a concentrated group until reaching the confluence of the Grande Ronde and Snake Rivers. Upon entering the Snake River, individual fish delayed for varying periods, causing population dispersal.

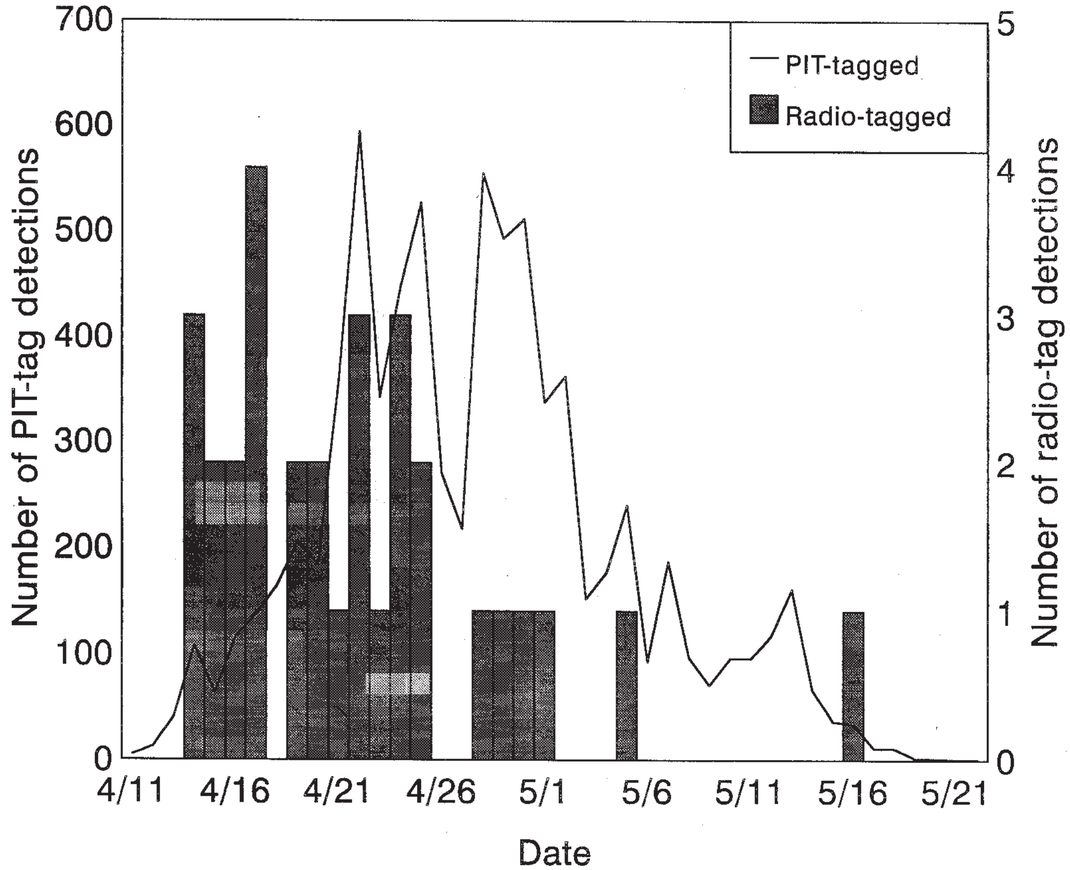

Figure 7. Lower Granite Dam detection distributions of PIT- and radio-tagged Lookingglass Hatchery juvenile chinook salmon, 1997.

Actively migrating juvenile salmon are expected to be relatively safe from predation because they occupy areas of higher flow within streams and rivers. When they delay, they typically move into areas of lower water velocity making them more vulnerable to predation. We identified two areas of relatively high mortality for radio-tagged fish between release and the head of Lower Granite Reservoir. The first area was in Lookingglass Creek near the hatchery. This area accounted for 52.6% of the observed mortality during migration. The second high mortality area was a 23-km section of the Snake River downstream from the confluence from the Grande Ronde and Snake Rivers, accounting for 31.6% of the observed mortality. The overall migration rate in the upper section of this 23-km section (between monitoring Sites 8 and 9) was high. However, all fish that delayed within this area were subsequently identified as mortalities. Fish with lower migration rates in both of these reaches may have been more susceptible to predation, though causes of mortality within these areas were not determined. Effects of tagging may also have contributed to the high observed mortality in Lookingglass Creek.

The hatchery environment results in artificially high survival prior to release, postponing natural culling until after release (Waples 1991). Disease, particularly bacterial kidney disease (*Renibacterium salmoninarum*) (BKD), is prevalent in anadromous salmonids throughout the Snake River Basin and has been shown to increase in severity during migration (Maule et al. 1996). In addition, present hatchery release strategies result in large concentrations of juvenile salmonids (Waples 1991) that predators can rapidly exploit (Collis et al. 1995, Shively et al. 1996).

No mortalities were observed in the area of transition between the free-flowing Snake River and the slack water of Lower Granite Reservoir, though this was possibly due to the higher than average Snake River flows during the 1997 juvenile chinook salmon migration. In 1996, U.S. Fish and Wildlife Service (USFWS) personnel observed large concentrations of hatchery yearling chinook salmon staging in the transition area between the free-flowing Snake River and Lower Granite Reservoir (between Asotin, WA and the Snake River smolt monitoring trap) (W. Connor, USFWS, pers. commun., August 1996). This area is similar to that described in the Clearwater River by Shively et al. (1996), where an increase in predation by northern squawfish (*Ptychocheilus oregonensis*) was noted after hatchery smolts arrived shortly after release from Dworshak National Fish Hatchery.

A secondary objective of this study was to evaluate the effects of radio tags on fish performance. Radio telemetry is a useful tool for gathering information on fish movement and behavior. With listing of many Columbia River Basin salmonid stocks under the Endangered Species Act, the use of radio telemetry to evaluate juvenile salmonid behavior has increased substantially in recent years (Adams et al. 1996, 1998; Hensleigh et al. 1997), due in part to the small sample sizes needed. However, the information collected using radio telemetry is only useful if the radio-tagged fish are representative of the untagged population. This requires minimal effects of the presence of the tag or the tagging procedure. Numerous studies have been conducted on the effects of radio tags attached externally, implanted gastrically, or implanted surgically on swimming performance, growth weight, feeding behavior, predator avoidance, and survival (Mellas and Haynes 1985; Greenstreet and Morgan 1989; Lucas 1989; Moore et al. 1990; Adams et al. 1997, 1998; Martinelli et al. 1998). However, most of these evaluations were conducted in laboratory tanks. Evaluations in the field did not compare radio-tagged fish performance to that of fish not radio-tagged.

Use of combination radio/PIT tags in our study allowed comparison of these fish to fish that were only PIT-tagged. The results indicate the presence of the radio tag significantly affected survival, travel time, and growth. This result was not surprising since conditions that smolts face in the wild (feeding and predator avoidance) are less forgiving than conditions in a laboratory setting. However, we used a larger radio tag than those used by some other researchers. Furthermore, relying on PIT-tag detections at dams downstream from the immediate study area (and area of interest) for comparisons of performance between the two groups may have exaggerated the tag's negative effects on performance.

Our study provided preliminary information on where post-hatchery-release mortality occurred for yearling chinook salmon released from Lookingglass Hatchery. Future studies may focus efforts on these areas. We believe the high pre-release mortality for radio-tagged fish was in part due to BKD, possibly aggravated by stress associated with the surgical implant technique. The use of smaller radio tags and an abbreviated pre-release post-surgical recovery time might reduce the stress associated with tagging and the susceptibility to BKD.

Additional research designed to precisely determine locations, timing, and sources of mortality to hatchery yearling chinook salmon between release at hatcheries and the head of Lower Granite Reservoir is needed. Future studies might include releasing PIT-tagged smolts to precisely estimate survival through various reaches, examining the responses of predator populations to hatchery releases, evaluating different hatchery rearing practices or release strategies, and the effects of management strategies such as flow augmentation and drawdown on migrational behavior and survival.

RECOMMENDATIONS

The results of the 1997 study formed the basis for the following recommendations for 1998 and future years:

1) Continue to evaluate radio-tag effects on survival, travel time, and growth between radio-tagged and PIT-tagged Lookingglass Hatchery yearling chinook salmon between release and the tailrace of Lower Granite Dam. Future studies should use smaller radio transmitters, modify tagging methods to reduce stress associated with radio tagging, and reduce pre-release recovery time to limit BKD exposure.

2) Increase the number of functional radio transmitters released and add more fixed-site telemetry receivers in areas where migrational mortality was high.

3) Continue releases of PIT-tagged smolts from each Snake River Basin hatchery so that survival can be estimated to Lower Granite Dam each year.

4) Coordinate future studies with other inriver projects to maximize information gain while minimizing effects on salmonid resources.

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Appendix Table 1. Estimated survival probabilities for juivenile steelhead (hatchery and wild combined) detected and returned to or PIT tagged and released into the tailrace of Lower Granite Dam in 1997. Daily groups pooled as necessary to calculate estimates. Estimates based on the Single-Release Model. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-MCNary Dam; Rel.-Release; Est.-Estimate; s.e.-standard error.

	Survival Estimates										
	LGR-LGO		LGO-LMO		LGR-LMO			LMO-MCN		LGR-MCN	
Rel. Date	Est.	s.e.	Est.	s.e.	Est.	s.e.	Rel. Date	Est.	s.e.	Est.	s.e.
07 Apr 97	1.000	0.527	0.800	0.716	0.800	0.513	07-11 Apr 97	1.299	1.239	1.229	1.127
08 Apr 97	0.706	0.147	2.625	2.333	1.854	1.615					
09 Apr 97	0.597	0.189	1.350	1.063	0.806	0.606					
10 Apr 97	1.240	0.257	0.844	0.394	1.047	0.424					
11 Apr 97	1.000	0.373	0.542	0.305	0.542	0.228					
12 Apr 97	0.762	0.160	1.467	0.702	1.117	0.513	12 Apr 97	0.571	0.503	0.639	0.465
13 Apr 97	1.415	0.318	0.551	0.248	0.779	0.282	13-14 Apr 97	0.565	0.525	0.727	0.637
14 Apr 97	0.846	0.070	2.168	0.959	1.833	0.809					
15 Apr 97	0.945	0.074	0.720	0.115	0.680	0.095	15 Apr 97	0.750	0.453	0.510	0.301
16 Apr 97	0.887	0.054	1.047	0.189	0.929	0.161	16-17 Apr 97	1.082	0.497	0.932	0.417
17 Apr 97	0.982	0.057	0.826	0.123	0.811	0.111					
18 Apr 97	0.859	0.051	1.486	0.418	1.277	0.354	18 Apr 97	1.115	1.092	1.424	1.334
19 Apr 97	1.025	0.045	0.788	0.099	0.808	0.094	19 Apr 97	1.230	0.643	0.993	0.507
20 Apr 97	0.977	0.044	0.947	0.114	0.925	0.103	20 Apr 97	0.539	0.180	0.499	0.157
21 Apr 97	1.027	0.028	0.841	0.057	0.864	0.053	21 Apr 97	0.807	0.174	0.697	0.145
22 Apr 97	0.971	0.042	0.886	0.105	0.860	0.095	22 Apr 97	2.069	1.404	1.779	1.192
23 Apr 97	0.950	0.034	0.979	0.084	0.930	0.073	23 Apr 97	0.636	0.164	0.592	0.146
24 Apr 97	0.941	0.036	0.966	0.087	0.909	0.074	24 Apr 97	0.638	0.172	0.580	0.150
25 Apr 97	1.053	0.037	0.820	0.069	0.864	0.062	25 Apr 97	0.469	0.095	0.405	0.077
26 Apr 97	0.967	0.037	1.108	0.119	1.071	0.105	26 Apr 97	0.713	0.248	0.764	0.255
27 Apr 97	1.028	0.088	0.867	0.135	0.891	0.111	27 Apr 97	0.542	0.191	0.483	0.160
28 Apr 97	1.039	0.059	0.871	0.114	0.905	0.104	28 Apr 97	0.782	0.302	0.708	0.262
29 Apr 97	0.944	0.022	0.899	0.056	0.848	0.049	29 Apr 97	0.924	0.232	0.783	0.192
30 Apr 97	0.946	0.023	0.928	0.054	0.878	0.046	30 Apr 97	1.102	0.292	0.967	0.252

Appendix Table 1. Continued.

	Survival Estimates										
	LGR-LGO		LGO-LMO		LGR-LMO			LMO-MCN		LGR-MCN	
Rel. Date	Est.	s.e.	Est.	s.e.	Est.	s.e.	Rel. Date	Est.	s.e.	Est.	s.e.
01 May 97	0.970	0.023	0.896	0.048	0.869	0.041	01 May 97	0.618	0.118	0.537	0.099
02 May 97	0.973	0.020	0.944	0.054	0.918	0.049	02 May 97	0.684	0.154	0.628	0.137
03 May 97	1.019	0.025	0.793	0.043	0.809	0.039	03 May 97	2.106	0.902	1.703	0.725
04 May 97	0.929	0.038	0.883	0.101	0.820	0.089	04 May 97	0.744	0.329	0.610	0.262
05 May 97	1.048	0.058	0.709	0.093	0.743	0.087	05-06 May 97	1.030	0.341	0.868	0.282
06 May 97	0.970	0.026	0.897	0.067	0.870	0.060					
07 May 97	0.945	0.022	0.982	0.079	0.927	0.072	07 May 97	0.698	0.215	0.647	0.193
08 May 97	0.924	0.024	1.149	0.113	1.062	0.101	08 May 97	1.597	0.900	1.696	0.942
09 May 97	0.962	0.028	0.844	0.063	0.812	0.056	09 May 97	0.964	0.342	0.782	0.272
10 May 97	0.952	0.032	1.162	0.127	1.105	0.115	10 May 97	0.712	0.303	0.787	0.325
11 May 97	0.873	0.088	1.006	0.208	0.878	0.160	11 May 97	1.285	1.226	1.128	1.057
12 May 97	1.043	0.096	0.717	0.138	0.748	0.125	12 May 97	0.867	0.808	0.648	0.595
13 May 97	1.015	0.043	0.852	0.095	0.865	0.088	13 May 97	0.888	0.378	0.768	0.317
14 May 97	0.989	0.045	1.079	0.178	1.067	0.169	14 May 97	2.578	2.564	2.751	2.700
15 May 97	0.923	0.049	0.850	0.117	0.785	0.100	15 May 97	1.533	0.862	1.204	0.659
16 May 97	0.910	0.044	0.942	0.120	0.857	0.101	16 May 97	1.032	0.444	0.884	0.366
17 May 97	0.964	0.057	0.947	0.131	0.913	0.114	17 May 97	1.031	0.496	0.941	0.437
18 May 97	0.758	0.090	1.332	0.547	1.010	0.400	18 May 97	0.348	0.334	0.351	0.306
19 May 97	0.936	0.116	5.327	5.027	4.984	4.665	19-20 May 97	2.014	1.958	1.893	1.819
20 May 97	0.929	0.074	0.813	0.128	0.755	0.102					
21 May 97	1.048	0.092	0.668	0.102	0.700	0.085	21-23 May 97	4.807	4.737	3.486	3.426
22 May 97	1.000	0.072	0.667	0.111	0.667	0.100					
23 May 97	0.993	0.062	0.796	0.101	0.790	0.087					
24 May 97	1.039	0.062	0.733	0.124	0.762	0.119	24-25 May 97	1.084	1.045	1.002	0.953
25 May 97	0.825	0.066	2.176	1.090	1.795	0.892					
26 May 97	0.935	0.098	0.911	0.277	0.852	0.242	26 May 97	0.274	0.171	0.234	0.129
27 May 97	0.906	0.066	0.905	0.128	0.820	0.101	27 May 97	1.068	0.979	0.875	0.796
28 May 97	0.996	0.091	0.897	0.204	0.893	0.185	28 May 97	0.539	0.492	0.481	0.428
29 May 97	0.835	0.079	1.265	0.519	1.056	0.424	29-30 May 97	1.393	1.336	0.973	0.919
30 May 97	0.837	0.074	0.698	0.138	0.585	0.105					
31 May 97	0.942	0.082	0.534	0.124	0.503	0.108	31 May 97	0.301	0.264	0.151	0.129
Weighted Mean	**0.966**	**0.006**	**0.902**	**0.020**	**0.871**	**0.016**		**0.834**	**0.065**	**0.728**	**0.053**

Appendix Table 2. Estimated survival probabilities for yearling chinook salmon (hatchery and wild combined) detected and returned to the tailrace of Lower Granite Dam in 1997. Daily groups pooled as necessary to calculate estimates. Estimates based on the Single-Release Model. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-MCNary Dam; Rel.-Release; Est.-Estimate; s.e.-standard error.

	Survival Estimates										
	LGR-LGO		LGO-LMO		LGR-LMO			LMO-MCN		LGR-MCN	
Rel. Date	Est.	s.e.	Est.	s.e.	Est.	s.e.	Rel. Date	Est.	s.e.	Est.	s.e.
06 Apr 97	0.714	0.220	1.200	0.890	0.857	0.613	06-07 Apr 97	0.762	0.580	0.552	0.376
07 Apr 97	0.817	0.202	0.816	0.378	0.667	0.285					
08-09 Apr 97	1.081	0.415	0.686	0.353	0.742	0.237	08-12 Apr 97	1.254	1.133	1.021	0.909
10 Apr 97	0.715	0.111	0.844	0.245	0.603	0.168					
11 Apr 97	0.898	0.111	0.856	0.225	0.769	0.185					
12 Apr 97	0.777	0.104	1.594	0.707	1.238	0.539					
13 Apr 97	1.075	0.181	0.702	0.240	0.754	0.220	13-14 Apr 97	0.573	0.527	0.629	0.535
14 Apr 97	1.082	0.192	2.415	2.237	2.613	2.366					
15-16 Apr 97	1.143	0.181	1.313	0.805	1.501	0.883	15-19 Apr 97	0.520	0.361	0.672	0.431
17 Apr 97	0.898	0.122	2.240	2.049	2.013	1.822					
18 Apr 97	0.655	0.081	1.983	0.969	1.299	0.626					
19 Apr 97	1.128	0.161	0.871	0.371	0.982	0.391					
20 Apr 97	1.215	0.252	0.415	0.110	0.504	0.077	20-21 Apr 97	1.371	0.719	0.946	0.479
21 Apr 97	0.911	0.098	1.245	0.409	1.135	0.352					
22 Apr 97	0.915	0.086	0.797	0.154	0.729	0.124	22 Apr 97	0.505	0.242	0.368	0.166
23 Apr 97	0.936	0.128	0.760	0.167	0.712	0.123	23 Apr 97	2.129	2.007	1.515	1.408
24 Apr 97	0.854	0.095	0.878	0.166	0.750	0.120	24-25 Apr 97	1.648	1.106	1.450	0.955
25 Apr 97	0.906	0.082	1.113	0.251	1.008	0.209					
26 Apr 97	0.892	0.090	0.982	0.220	0.876	0.177	26 Apr 97	1.588	1.490	1.391	1.276
27 Apr 97	1.058	0.127	0.888	0.258	0.939	0.246	27-28 Apr 97	1.925	1.301	1.666	1.105
28 Apr 97	1.113	0.106	0.755	0.136	0.840	0.125					
29 Apr 97	0.853	0.070	1.003	0.174	0.856	0.134	29 Apr 97	0.858	0.553	0.734	0.460
30 Apr 97	0.877	0.067	0.717	0.105	0.629	0.080	30 Apr 97	0.681	0.406	0.428	0.251

Appendix Table 2. Continued.

	Survival Estimates										
	LGR-LGO		LGO-LMO		LGR-LMO			LMO-MCN		LGR-MCN	
Rel. Date	Est.	s.e.	Est.	s.e.	Est.	s.e.	Rel. Date	Est.	s.e.	Est.	s.e.
01 May 97	0.925	0.073	0.976	0.192	0.902	0.164	01 May 97	0.624	0.392	0.563	0.338
02 May 97	0.953	0.081	0.642	0.127	0.612	0.110	02 May 97	0.351	0.163	0.215	0.093
03 May 97	0.986	0.123	1.123	0.483	1.108	0.455	03 May 97	0.304	0.286	0.337	0.285
04 May 97	1.249	0.173	0.712	0.201	0.890	0.215	04 May 97	0.709	0.470	0.631	0.390
05 May 97	0.936	0.085	0.810	0.209	0.758	0.184	05-06 May 97	0.469	0.313	0.433	0.269
06 May 97	1.143	0.185	2.159	2.032	2.468	2.286					
07 May 97	0.983	0.127	1.949	1.047	1.916	0.999	07 May 97	0.292	0.305	0.559	0.504
08 May 97	0.921	0.140	1.502	0.785	1.384	0.693	08 May 97	0.306	0.303	0.423	0.360
09 May 97	0.994	0.147	0.765	0.286	0.761	0.261	09-10 May 97	0.569	0.533	0.458	0.413
10 May 97	1.082	0.225	0.787	0.357	0.852	0.341					
11 May 97	0.823	0.159	0.905	0.406	0.745	0.304	11 May 97	0.752	0.738	0.561	0.501
12 May 97	1.031	0.191	0.685	0.266	0.706	0.241	12 May 97	0.540	0.381	0.381	0.236
13 May 97	0.924	0.114	0.916	0.369	0.846	0.324	13 May 97	1.015	1.040	1.230	1.188
14 May 97	0.968	0.120	2.191	1.483	2.122	1.411	14 May 97				
15 May 97	0.902	0.116	1.686	0.897	1.521	0.784	15 May 97	0.317	0.331	0.483	0.436
16 May 97	1.321	0.307	0.521	0.225	0.688	0.245	16 May 97	1.083	1.071	0.745	0.686
17 May 97	1.217	0.353	0.706	0.396	0.859	0.405	17-18 May 97	0.628	0.622	0.626	0.581
18 May 97	1.312	0.283	0.866	0.471	1.136	0.563					
19 May 97	0.935	0.178	1.410	0.715	1.319	0.622	19 May 97	0.333	0.323	0.440	0.371
20 May 97	0.646	0.140	0.733	0.304	0.474	0.180	20-21 May 97	0.683	0.616	0.442	0.385
21 May 97	0.892	0.150	0.837	0.308	0.746	0.246					
22-23 May 97	0.794	0.142	2.023	1.837	1.605	1.431	22-31 May 97	0.370	0.355	0.373	0.335
24 May 97	0.936	0.197	0.851	0.594	0.796	0.530					
25 May 97	0.500	0.192	1.556	1.278	0.778	0.592					
26 May 97	0.917	0.238	0.703	0.335	0.645	0.258					
27-31 May 97	1.295	0.434	1.171	1.135	1.516	1.365					
Weighted Mean	**0.942**	**0.018**	**0.894**	**0.042**	**0.810**	**0.036**		**0.798**	**0.091**	**0.653**	**0.072**